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TEST AND EVALUATION IN THE UNITED STATES NAVY, AND HOW IT MUST EVOLVE TO SUPPORT FUTURE SYSTEMS ACQUISITION

by

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September 2003

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Modern Test and Evaluation has long supported acquisition of warfighting systems in the United States Navy. As the complexity and long-term supportability of these systems has dramatically increased, the need to successfully, and incrementally test and evaluate families of systems, including their interfaces, has become even more critical. Long established techniques and methodologies for T&E may still apply, but new factors must be addressed. As the Navy continues to grapple with acquisition reform, and also looks to transform itself in the future, the Warfighters' needs have essentially remained the same – delivery of the best, most effective weapons, delivered as soon as possible, and made easy to operate and maintain. Without an equally effective developmental and operational test and evaluation process, the United States Navy cannot satisfy this need.

This thesis examines T&E today and where it must go in the future. It provides recommendations for T&E enhancements, and explores several areas where the Navy, and in many cases, Joint Services, are already looking towards future, integrated and collaborative test and evaluation.

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TEST AND EVALUATION IN THE UNITED STATES NAVY, AND HOW IT MUST EVOLVE TO SUPPORT FUTURE SYSTEMS ACQUISITION

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LIST OF ACRONYMS

ACAT	Acquisition Category
ACTD	Advanced Concept Technology Demonstration
APM	Acquisition Program Manager
ASN(RD&A)	Office of the Assistant Secretary of the Navy, Research Development & Acquisition
ATD	Advanced Technology Demonstration
CDR	Critical Design Review
CINC	Commander In Chief
CI/NDI	Commercial Item / Non-Developmental Item
CJCS	Chairman of the Joint Chiefs of Staff
CMM	Capability Maturity Model
CNO	Chief Naval Operations
COMOPTEVFOR	Commander, Operational Test and Evaluation Force
CORBA	Common Object Request Broker Architecture
COTS	Commercial-Off-The-Shelf
CSRD	Computing System Requirements Document
CPU	Central Processing Unit
DA	Developing Activity or Design Agent
DAB	Defense Acquisition Board
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DAWIA	Defense Acquisition Workforce Improvement Act
DCOM	Distributed Component Object Model
DDG	Destroyer, Guided Missile
DII COE	Defense Information Infrastructure Common Operating Environment
DMS	Diminished Manufacturing Source
DOD	Department of Defense
DON	Department of the Navy
DRM	Dynamic Resource Management
DSB	Defense Science Board
DSMC	Defense Systems Management College
DT	Developmental Test
EDM	Engineering Development Model
EMD	Engineering & Manufacturing Development
FAR	Federal Acquisition Regulation
FCS	Fire Control System
HiPer-D	Hi Performance Distributed Computing
HSI	Human Systems Integration
IBR	Integrated Baseline Review
IDE	Integrated Development Environment
IDL	Interface Design Language

IEEE	Institute of Electrical and Electronics Engineers
IMS	Integrated Master Schedule
IOC	Initial Operating Capability
I/O	Input Output
IOP	I/O Processor
IPPD	Integrated Product & Process Development
IPT	Integrated Product Team
KPA	Key Process Area
MOE	Measures of Effectiveness
MOP	Measures of Performance
MOS	Measures of Suitability
MS	Milestone
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NDI	Non-Developmental Item
NOA	Navy Open Architecture
NOACE	Navy Open Architecture Computing Environment
NWS	Naval Warfare Systems
OO	Object Oriented
OPEVAL	Operational Evaluation
ORTS	Operational Readiness Test System
OS	Operating System
OSJTF	Open Systems Joint Task Force
OT	Operational Test
OTDG	Operational Test Director's Guide
P(f)	Probability of Occurrence
P-CMM	People Capability Maturity Model
PDR	Preliminary Design Review
PEO	Program Executive Officer
PEO IWS	Program Executive Officer Integrated Warfare Systems
PM	Program Manager
POA&M	Plan of Action and Milestones
PQM	Production, Quality and Manufacturing
PRA	Probabilistic Risk Assessment
PRR	Production Readiness Review
R&D	Research and Development
SA-CMM	Software Acquisition Capability Maturity Model
SECNAV	Secretary of the Navy
SEI	Software Engineering Institute
SEMT	Systems Engineering Management Team
SFR	Systems Functional Review

SOO	Statement of Objectives
SPAWAR	Space and Naval Warfare Systems Command
SPRDE	Systems Planning, Research, Development, and Engineering
SRR	Systems Requirements Review
SVR	Systems Verification Review
SW-CMM	Software Capability Maturity Model
TDA	Technical Direction Agent
T&E	Test and Evaluation
TPM	Technical Performance Measure

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EXECUTIVE SUMMARY

Test and Evaluation (T&E) is required by law and contract for all major Department of Defense (DOD) acquisition programs. The science of T&E is currently taught to a portion of the Defense Acquisition Workforce, in the career field of T&E. The culture of T&E is embedded in the corporate history of all those who struggled to defend the need to both test and evaluate complex, critical weapons and combat systems being developed and fielded by the United States Department of Defense. As the DOD continues to transform itself, so must the T&E community keep up with the many challenges of this transformation, including the advent of evolutionary acquisition (spiral and incremental development) and development in an open architecture environment.

This paper strives to provide a stamp in time of what the T&E community has been doing, what it is currently doing, and what can be done in the future to keep pace and to ensure that weapon systems acquired on behalf of every U.S. taxpayer are tested and evaluated in a manner that will deliver these weapons to our warfighters as quickly and efficiently as possible. It is also the responsibility of this same community to assure that the systems delivered are the best possible and will protect the lives of those on the front lines. And given rapid deployment of these weapon systems, we must ensure these systems perform as our soldiers, sailors and airmen need them to.

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I. INTRODUCTION

A. BACKGROUND

Systems have been tested in the United States since the first weapons were developed for this country's use in defending itself, however modern testing could be associated with the advent of nuclear energy. The nuclear weapons age began on July 16, 1945 when the U.S. exploded the first nuclear bomb, codenamed 'Trinity' at Alamogordo, New Mexico. The "thermonuclear age" began on November 1, 1952 when the U.S. exploded the first thermonuclear bomb at Eniwetok atoll in the Pacific. Codenamed 'Mike', this bomb was 500 times more powerful than the 'Trinity' test and had an estimated yield of 10.4 megatons.

Figure 1. Nuclear bomb test Priscilla, June 24, 1957

According to the environmental lobby Greenpeace, the U.S. has carried out 1,030 nuclear weapons tests (the last

and final test on 23 September 1993); the equivalent of one nuclear weapons test every 17 days since its first test (Campaign History, 2002.) These test were planned to be successful. Each test was a step in an overall master test plan that would guarantee success of the program while maintaining a broad enough region of uncertainty to compensate for the unexpected. These were extremely regimented programs. While certainly a formidable challenge to appropriately test nuclear weapons, this paper will focus on conventional (non-nuclear) Department of Navy (DON) weapon systems under DOD development.

For the purpose of this research, and as defined in the original version (dated December 1996) of SECNAVINST 5000.2B:

> A "weapon system" is an overarching term that applies to a host platform (e.g., ship, aircraft, missile, weapon, combat system subsystem(s), component(s), equipment(s), hardware, firmware, software, or item(s) that may collectively or individually be a weapon system acquisition program (i.e., all programs other than information technology programs).

B. PURPOSE

The purpose of this research is to provide a historical account of what has been done in the past, what is currently being accomplished, and what could be done in the future to ensure that every weapon system acquired on behalf of U.S. taxpayers is tested and evaluated in a manner that will deliver these weapons to our warfighters as quickly and efficiently as possible. And given rapid deployment of these weapon systems, DOD must ensure they work as our soldiers, sailors, and airmen need them to.

This research will examine several factors that should prompt an evolution in how modern T&E must be conducted. T&E must continue to support the many DOD weapon systems under acquisition at present, and within the coming decade, but it must be agile enough to accommodate future, open weapon systems, which will have potentially different sets of requirements and risks to be weighed only through conscientious and appropriate testing and evaluation.

C. RESEARCH QUESTIONS

The intent of this research study is to focus on a variety of questions, some in depth, and others less so, to build a case that test and evaluation (T&E) as it is conducted today, must evolve to keep pace with the DOD as it undergoes reform, transformation, perpetually shifting requirements, budget fluxuations, and an emerging and dangerous new set of enemies and unforeseen threats. This set of questions can be grouped into four themes, including history and the present, guidance and leadership, open systems, and T&E in the future.

History and the Present:

- How are Navy weapon systems acquired today?
- How are US Navy surface combatant weapon systems evolved today?
- What is Test and Evaluation, and how is it conducted in today’s Navy?

Guidance and Leadership:

- What is acquisition reform, and how does it apply to T&E?
- What does Transformation mean with respect to T&E?
- What do current Navy Leaders think about T&E today?

Open Systems:

- What are "open systems"?
- What is "open architecture" and what is the Navy's commitment to OA?
- How will OA improve weapon systems in the future?
- What are recent improvements to OA?
- What are the advantages and disadvantages of OA?
- What are examples of existing OA systems?

T&E in the Future:

- What is required to properly test and evaluate future Navy systems?
- What are the recent changes in the methodology of weapon systems computer program development?
- How are Joint systems tested and evaluated?
- What is evolutionary acquisition, and how does it apply to T&E of those future systems?
- How should T&E be taught to ensure future T&E professionals would be prepared for future challenges?
- How must T&E evolve in the future?

It should be noted that the AEGIS program (specifically the AEGIS platform, the AEGIS Weapon Systems, and the AEGIS Weapon System Computer Program) will be used extensively as a case study when exploring many of the questions stated above. In addition, some attention will be focused towards the Missile Defense Agency, however mainly as it relates to the AEGIS Ballistic Missile Defense (ABMD) development effort.

D. POTENTIAL BENEFITS FROM THIS STUDY

As a member of the T&E acquisition workforce, and a T&E practitioner for approximately the last 15 years, the author's sincere hope is that there will be several benefits from this research study. This research shall provide recommendations and assessments to both DON and the T&E professional acquisition workforce on what can be done to prepare for testing of future, open systems.

In addition, this research is hoped to have actual benefit to the Warfighters of the future, who will depend on timely and appropriate testing and evaluation, leading to weapons on target, and the ability to fight and win, unhampered by systems which offer technology, but are not suitably tested and ready to go into harms way.

E. SCOPE AND METHODOLOGY

1. Scope

The scope of this research study is divided into five parts. The first part is the introduction, and includes a brief discussion on DOD acquisition, acquisition reform, T&E, and what open systems means to DOD and how the rush to get state-of-the-art, open systems to the Warfighter, presents a unique set of challenges to both testers and evaluators.

The second part involves a historical review of test and evaluation, touching on the acquisition reform discussion from the background section, but going into more detail. This section will expand on the history of T&E, T&E guidance, and T&E in practice today. This section will

also include a short discussion about where T&E needs to go in the future, which is expanded in much greater detail in section four.

The third part will focus on open systems and open architecture, including current guidance as related to DOD systems under acquisition today and standards for open architecture, applicable to weapon systems to be acquired in the future. This part will also discuss a few ongoing examples of system under current development, including the advantages, as well as challenges, of working with open systems.

The fourth part will use the findings from section three, to build a case for T&E in the future.

Finally, the fifth section will present conclusions and recommendations for further study.

The end result from this research is to contrast where modern T&E appears to be headed in the future and where it needs to go based on the latest published acquisition reform guidance, and based on where open systems development will effect future DOD development and future weapon systems undergoing T&E.

2. Methodology

The methodology used in this research consists of the following:

- Conduct a literature review of DOD and DON related guidance and reports on T&E and acquisition reform.
- Conduct an in-depth review of available Program Executive Office (PEO) level briefings and white papers covering acquisition reform, transformation,

and steps to address legacy systems, either in-service or currently under development and acquisition today.

- Interview members of the Acquisition Workforce, specifically, Test and Evaluation Professionals to assess their efforts to prepare for emerging, open systems to be developed.
- Interview members of various Program Executive Offices, who are presently involved in the acquisition of systems which will be "open" from the inception to assess their opinions on how prepared we will be to test and evaluate their systems in the future.
- Participate in T&E communities of practice, including the International Test and Evaluation Association (ITEA), and the Defense Test & Evaluation Professional Institute (DTEPI).
- Conduct in-depth Internet research on all topics to determine what information is in the public domain and to determine how commercially produced, open systems are tested and evaluated today.

F. ACQUISITION TODAY

Defense acquisition's primary objective is to obtain cost-effective, quality weapon systems, in a timely manner, while meeting an operational need. Today's modern warfighting systems are acquired under a series of DOD instructions, directives and regulations. The Secretary of the Navy implemented SECNAVINST 5000.2B in December of 1996 to provide a framework for mandatory procedures applicable to all major and minor DON acquisition programs.

Acquisition policy continues to evolve under what has commonly been referred to as acquisition reform. Even when SECNAVINST 5000.2B was written over seven years ago, its authors understood that acquisition would need to evolve further. In fact, the instruction referenced a term that would become a catch phrase for modern acquisition – "Evolutionary Acquisition."

As stated in SECNAVINST 5000.2B, "When an evolutionary acquisition (EA) strategy is used to field a core capability and there are subsequent modifications to the initial fielded core capability, such modifications shall satisfy a validated requirement and be supportable in the operational environment. EA modifications to the core capability shall be funded, developed, and tested in manageable increments. Each increment shall be managed as a modification."

Recently, the Secretary of Defense, Donald Rumsfeld called for a new Department of Defense acquisition system. In January of 2001 during a nomination hearing before the Senate Armed Services Committee, Secretary Rumsfeld (Canahuate, 2001, ¶2) said, "The present weapons systems acquisition process is ill-suited to meet the demands posed by an expansion of unconventional and asymmetrical threats in an era of rapid technological advances and pervasive proliferation." Later that same year, in October of 2002, Deputy Defense Secretary Paul Wolfowitz cancelled all existing acquisition rules, and stated that new ones should be prepared. At the time, he provided interim guidance pointing to a simpler system to "rapidly deliver affordable, sustainable capability to the warfighter that

meets the warfighter's needs. (Caterinicchia, 2003) Further, Secretary Wolfowitz' memo, spoke of "transforming" the military, and Defense Secretary Rumsfeld has urged civilian and military leaders to acquire new, high-tech systems. And once acquired, these systems must be rapidly delivered onto the battlefield.

DOD acquisition still faces challenges. In his March of 2003 resignation letter to President Bush, Undersecretary of Defense for Acquisition, Technology and Logistics, Edward "Pete" Aldridge Jr. summarized his top five goals for achieving "acquisition excellence" within DOD:

1) Improve the credibility and effectiveness of the acquisition and logistics support process.
2) Improve the morale and quality of the acquisition workforce.
3) Improve the health of the defense industrial base.
4) Support the decision process by rationalizing weapon systems and defense infrastructure with the new defense strategy.
5) Initiate high-leverage technologies that would provide the war-winning capabilities of the future.

"All in all I think we have made significant progress on accomplishing these five goals and setting in place the acquisition, technology and logistics support activities that you and Secretary [Donald] Rumsfeld want to have for DOD," his letter said (Caterinicchia, 2003, ¶4.)

G. EVOLUTIONARY ACQUISITION – EXAMPLE: MDA

The Missile Defense Agency (MDA), in July 2003, released the following information regarding its acquisition strategy (BMD Fiscal Year 2004 Budget, 2003, p. 2.)

> MDA is following an evolutionary acquisition strategy for the BMD System that effectively manages changes in the threat, changes in BMD System technologies, and progress in development and testing. Using Research, Development, Test and Evaluation (RDT&E) resources almost exclusively and in conjunction with an evolutionary approach, the strategy capitalizes on technological progression and provides for development, limited production, and deployment of initial BMD capabilities incrementally as soon as they are ready. Adopting an evolutionary acquisition model, the BMD System is constructed around a "Capability-based Block" approach. Each BMDS Block spans a two-year timeframe and continuously builds capability into the BMD System by introducing new sensor and weapon projects, and/or by augmenting and enhancing existing capabilities. As the new projects mature they will be integrated into the BMD System to increase the capability to respond to the evolving threat. BMDS Block management includes decision points at which activities will be evaluated on the basis of effectiveness within the overall system, technical risk, deployment schedule, and cost. From these decision points, developmental activities will be accelerated, modified, or terminated depending on progress and promise.

H. TEST AND EVALUTATION

Two broad types of testing, which will be discussed in this document, are used to assist DOD in meeting the goal of defense acquisition, as laid out in section I.F.

Developmental testing covers a wide range that includes component and systems engineering testing, as well as modeling and simulation. Developmental testing affords the first chance to assess performance and effectiveness of a weapon system against tolerances laid out in the analysis of alternatives. Operational testing will focus on performance of a fully integrated set of systems, ideally within a realistic operating environment. Testing at the operational level is the process by which DOD assesses whether a weapon system can satisfy planned capability before deciding to begin full-rate production. In addition, operational T&E uses independent assessment to determine if a system is effective and suitable for its particular application.

DT&E is required for all developmental acquisition programs. For DON programs, the Design Agent (DA) through contractor testing or government test and engineering activities shall conduct DT&E. Combined developmental testing/operational testing (DT/OT) shall be pursued whenever possible to reduce program costs, improve program schedule, and provide early visibility of performance issues.

The DOD Under Secretary for Defense Acquisition, Technology and Logistics (USD (AT&L)) / Defense Systems maintains a staff element responsible for assuring that DT&E programs are sound, well-executed and sufficiently address the modern warfighters' needs. USD (AT&L) refers to this group as Developmental Test & Evaluation. Their mission (DOT&E Mission Statement, 2003, p.1) is to ensure development of sound and well-executed test strategies

within DT&E programs, and to ensure that DT&E matures a program; allowing it a good chance of achieving it's critical operational design goals. This group also provides the focal point for DT&E policy under United States Code Title 10, Section 133.

As part of the T&E Best Practices Conference, sponsored by DT&E USD (AT&L), "T&E ensures our weapon systems perform as desired and meet warfighters' requirements. (Weapon systems must) work when and how they are supposed to."(Lockhart, Richard, Integrating Test and Evaluation, 2002) The role of T&E in the acquisition process is:

- Provide essential information on which to base acquisition decisions.
- Assess technical performance and system maturity.
- Provide indication of program's development progress.
- Provide information about risk and risk mitigation.
- Identify problems so they can be resolved early.
- Confirm weapon system's readiness to enter IOT&E.
- Advise on how best to use the system.
- Confirm weapon system meets user requirements.

I. CHALLENGES TO THE DOD

The DOD will always face major management challenges and program risks as it seeks to support and defend the Constitution of the United States; provide for the common defense of the nation, its citizens, and its allies; and protect and advance U.S. interests around the world.

In the latest report to Congress ("Major Management Challenges and Program Risks," 2003, p. 5) the GAO summarized these challenges into eight areas. Nearly all of the major challenges to DOD apply directly to Test and Evaluation. From the need to hire, train, sustain and maintain a T&E workforce, to having the necessary infrastructure (ranges, targets, services, etc.) in place to engage in meaningful T&E, to having proper budgets, and using technology, to keeping a mindful eye towards costs effectiveness and timeliness, and monitoring and reducing risk, it seems T&E's major challenges are simply a subset of what DOD needs to do to improve and complete its fundamental mission. The goal for the T&E community should be to help DOD along this continuous path of improvement.

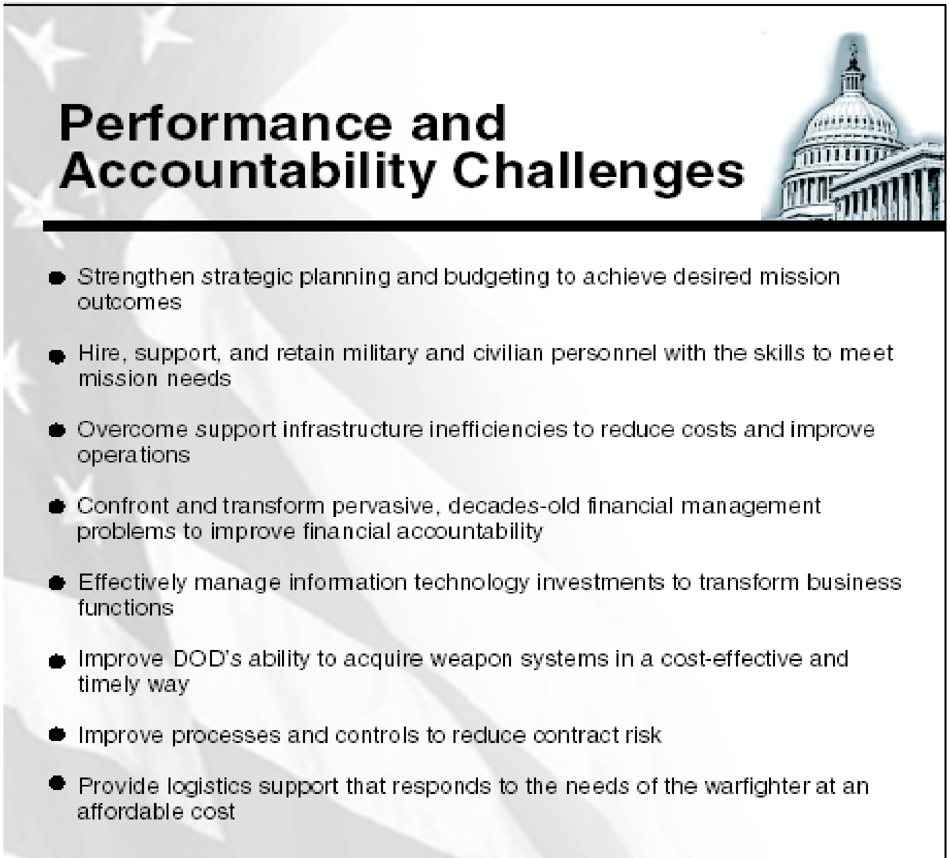

Figure 2. DOD Major Challenges (2003)

II. T&E: A HISTORICAL VIEWPOINT

A. LEADERSHIP PERSPECTIVE

Steadfast leadership by program development managers has brought us to where we are today. During the early days of nuclear power, without the strong and unfailing conviction of Admiral Hyman Rickover, who once said, "Good ideas are not adopted automatically. They must be driven into practice with courageous patience," the nuclear Navy might never have emerged into the uncontested force it remains today.

During the early days of Surface Missile Ship development, when existing weapon system were thought to be sufficient to meet the threat, RADM Wayne E. Meyer aggressively pushed for a fully-integrated weapon system. His "build a little, test a little, learn a lot," approach allowed the DON to field the most capable surface combatant ever.

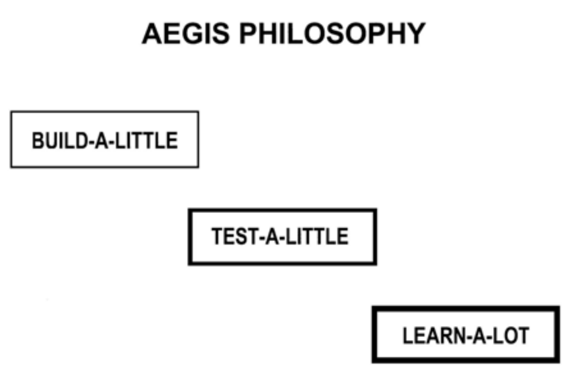

Figure 3. AEGIS System Engineering Philosophy (1977)

The Honorable William J. Perry, Secretary of Defense from 1994-1997 stated, "testing is the conscience of acquisition."

B. TEST AND EVALUTATION – IN THE NAVY

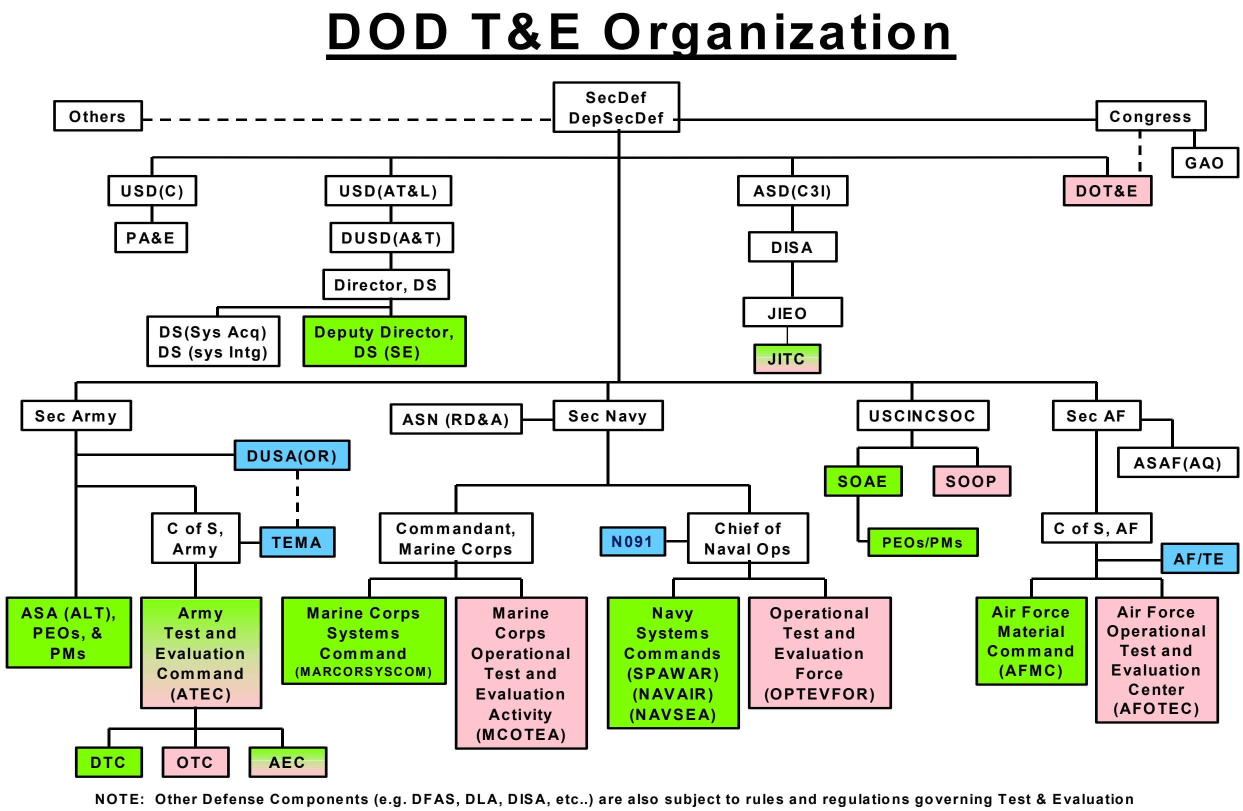

Figure 4. DOD T&E Organization (2003)

As defined in SECNAVINST 5000.2B, the following guidance is provided with respect to T&E: "Early involvement between the developing activity (DA) and the operational test agency (OTA) Operational Test and Evaluation Force (OPTEVFOR)/Marine Corps Operational Test and Evaluation Activity (MCOTEA) is required to ensure that both have a common understanding of the proposed system requirements and that developmental and operational testing is tailored to optimize cost, schedule, while verifying performance. The Commander, Marine Corps Systems Command

(COMMARCORSYSCOM) and Director, MCOTEA are the principals responsible for developmental test and evaluation (DT&E) and operational test and evaluation (OT&E), respectively, within the Marine Corps. MCOTEA is designated as the Marine Corps independent operational T&E activity responsible for adequate testing, objective evaluation, and independent reporting in support of the Marine Corps Acquisition Process.

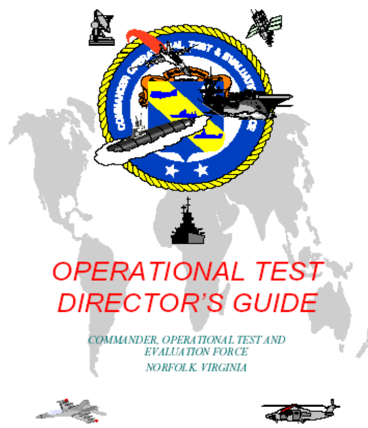

Figure 5. COTF OTD's Guide (2001)

The Operational Test Director's Guide is an instruction published and maintained by COMOPTEVFOR for the benefit of OTD's, OTC's and is a valuable reference for the entire DON T&E community. The OTDG is designed to provide the operational test director with guidance on the various aspects of operational test and evaluation.

C. TEST AND EVALUATION – AEGIS

1. Leading Up to AEGIS

During the World War II era, aircraft attacks against naval ships became a common threat. It became evident during this time that using small (20mm and 40mm) and medium (3" and 5") caliber man crew-served weapons against enemy air threats was not adequate to defend against the

threat. In addition, technological improvements in aircraft design overwhelmed current-day Anti-Aircraft capabilities of US naval defense systems. Foreign nations were creating faster, more maneuverable aircraft, more difficult to counter, and requiring greater manpower. Towards the end of WWII, a new threat was introduced when the first successful air-to-surface missiles became available. These computer-controlled missiles demonstrated vulnerability of the surface ships due to precision attacks. As a controlled experiment the Johns Hopkins University Applied Physics Laboratory (JHU/APL) started developing surface-to-air guided missile capabilities on TERRIER, TARTAR, and TALOS (AKA "3T") systems (Lundquist, 2002, ¶ 33.) The TALOS Fire Control System was a long range Beam-Rider system deployed on larger vessels including refurbished WWII vintage Cruisers. Second was the TERRIER system; a medium range fire control system deployed on smaller DLG's, (Large Destroyer/Light Cruiser). Finally was the TARTAR fire control system, a short-range missile system deployed on USS Adams DDG-2 class destroyers. These were truly the first ships specifically designed to handle a missile fire control system. When developed, the 3T's were intended as direct replacement for existing anti-air gun system. The radar system on these ships reported range, bearing, and elevation data, which was input to an analog computer that determined the range of open fire and generated the necessary orders for launching a missile into the radar guidance beam. The radar guidance beam guided the missile and developed the necessary steering instructions to intercept its target.

This phenomenal technology later became the basis for the state-of-the-art SPY radar system on current AEGIS Cruisers and Destroyers.

The standing Chief of Naval Operations, ADM Arleigh Burke, had recognized the need for surface-to-air missile systems with performance capabilities greater than the inherent capability of the 3T. Projected advances in threat speeds and the ability to be subject to coordinated mass attacks would still require an even faster reaction time and greater firepower resulting in a technologically advanced system to be called, "Typhon". Human reaction time was no longer sufficient to defend against attacks of larger magnitude and speed, and a computer-driven system was the answer for faster reaction time. The Bureau of Naval Weapons initiated Typhon in 1960. Most of the efforts during the development and testing of the Typhon system was to revolutionize the new radar system that was developed by the JHU/APL. The Typhon program developed principles needed to effectively build a more advanced weapons system. However, insufficient attention and emphasis were afforded to operational suitability and support requirements. The state-of-the-art technology available at the time was still too primitive to achieve the performance goals sought within appropriate size and weight requirements. Lessons learned from the Typhon project led to planning inception of the AEGIS program in 1963 (Madsen, 1986.)

By the late 1960's, the United States Navy realized that reaction time, firepower, and operational availability in various environments were not sufficient to counter

increasingly sophisticated enemy threats. The U.S. Navy's inability to adequately defend itself called for the proposal of a more advanced defense system. The Advanced Surface Missile System (ASMS) program began in 1965. Secretary of the Navy led a comprehensive engineering development program for ASMS. Following the cancellation of the Typhon program, the ASMS project was launched, later renamed AEGIS in 1969. AEGIS, which is a term used for the armor of Zeus (hence the phrase "under the aegis of" or "under the protection of"). Integrating still-evolving state-of-the-art radar and missile systems, AEGIS is a complete system designed to handle tactical engagements from detection through kill assessment. Designed as a fully integrated weapon system, it was built to defend against advanced air, surface, and subsurface threats. The AEGIS computer program is a set of operations controlling and operating the entire combat system. The AEGIS Weapon System computer program provides a fully automated response to threats (via selection and application of doctrine parameters), normal operation of Command and Decision (CND) process, and on-line system performance assessments. There are about one million words (using CMS-2Y language) in the computer programs for the AEGIS computer system using the UYK (General utilities Data processing Computing) processing unit.

2. Test Methodology

Prior to the introduction of the first AEGIS Cruiser the United States Navy had already developed a methodology for test and evaluation of Missile Fire Control Combat Systems. There were three distinct Missile Fire Control Systems deployed with fundamental differences between each.

First was the TALOS Fire Control System; the long-range beam-riding system deployed on larger vessels including refurbished WWII vintage cruisers. Second was the TERRIER system; a medium-range fire control system deployed on smaller DLG's, (Large Destroyer/Light Cruiser). The third was the TARTAR fire control system; a short-range missile system deployed on USS ADAMS (DDG-2) class destroyers. These were the first ships specifically designed to handle a missile fire control system (Lundquist, 2002, ¶ 33-35.)

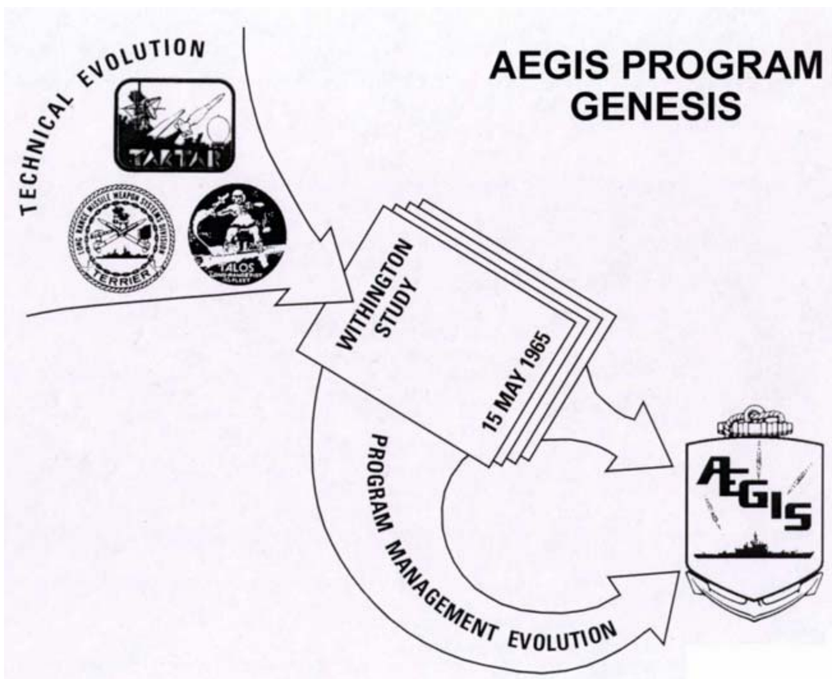

Figure 6. The AEGIS Program Genesis (1977)

From the 1960's through the early 1980's, these ships were the front line sea defense for the Navy's carrier battle groups. Most of these systems directly supported operations during the Vietnam Conflict and TERRIER and TALOS systems were credited with kills of hostile aircraft during that timeframe.

However these systems were designed with out-dated technology, requiring an extensive amount of maintenance to remain operational. Included in this maintenance was the assembly of missile parts prior to positioning on the launcher rail for firing. Computers were analog, (syncros, servos, gears and other discrete components) and required constant adjustment and alignment to maintain material readiness. It was not until the late 1970's, when the Navy's MK-1219 digital computer, (the first digital missile fire control computer) was retrofitted into existing systems. Insertion of technology was done similarly for years to come.

Testing directly on the platform, during major upgrades and revisions became the foundation of the test and evaluation process for many years to come. This philosophy was based on emerging technology and an ever-evolving threat.

Weapon systems, new and old, had to be maintained and tested. Each ship was evaluated against minimum standards to determine battle readiness. These "first generation" missile-guidance ships were evaluated very much like earlier ships, except that special tests were included to verify performance of the fire control system.

Each ship was evaluated first on maintenance. These early missile systems required a significant level of maintenance, which kept the crew very busy. During evaluation periods, maintenance actions were randomly inspected along with the maintenance paper work and documentation as well as crew training to perform the task.

For ships undergoing new construction, or coming through a major overhaul period, (every three years at that time), a Refresher Training, (REFTRA), and Combat Systems Ships Qualification Test, (CSSQT) were added to the ships schedule. CSSQT could be described as the first and only end-to-end combat system training. These training and test evolution periods had to be completed before deployment, and failure due to lack of training or system deficiency was a serious matter. Standards of evaluation were very high for these Naval Combatants. These ships were independently tested and integrated units that would later be required to operate in a battle group.

3. At-Sea Testing

During new construction or ship refurbishment, components of the new weapon system are assembled and integrated for the first time when they are installed on the ship. Previously, each element had been individually tested in the factory, where each piece of equipment met standards of construction and performance. This was the only insurance that these components would integrate properly within a functional weapon system.

Integration was carried out on the waterfront; a process where all the weapon system elements came together and were tested as a system for the first time. The measurement of this integration was conducted during a daily maintenance action called a DSOT, or Daily System Operability Test. This test included the generation of a simulated target, the assignment of radar, the training out of the launcher, and the loading of a test missile where firing voltage was applied and a tail cone light

illuminated if the circuit was complete. This test verified system performance, each day.

FY 75 CONGRESSIONAL CRITERIA FOR AEGIS

"The conferees concur in the fact that subsequent authorization requests for Aegis will be predicated upon:

- Successful at-sea testing that demonstrates the ability of Aegis to meet its prescribed performance objectives...
- At-sea operation and maintenance of the Aegis system by shipboard personnel...
- A cohesive integration plan specifying the interface of Aegis with the platform(s) and other weapon and command/control systems...
- Definition and approval by both the Navy and the Department of Defense of the platform(s) for Aegis..."

CONGRESSIONAL RECORD — HOUSE
JULY 24, 1974

Figure 7. Congressional Criteria for AEGIS (FY75)

Integration on the waterfront was costly, requiring the numerous support engineers and shipyard workers to make it all work. The effort also took time, but proved to be the most effective way to integrate weapon systems in those days. Due to the many unique features of each respective ship, waterfront integration became a "living process." Within this process was conceived the notion that performance of a "Class Of Ships" could only be realized based on "Individual Hull" trend performance. This meant that class requirements could be applied, as milestones, for each individual ship to satisfy. However, compliance to these standards differed vastly from ship to ship. While some ships demonstrated superior tracking radar

performance, others enjoyed stable launching systems. Mean Time Between Failure (MTBF) was dependent on crew training and aggressive diligence to maintenance procedures.

Across all phases of integration and test, at-sea testing of ships remained the best measure of performance. Ships were not certified for deployment unless successfully completing REFTRA and CSSQT. CSSQT required live firing at a target. CSSQT, although centered on a single ship, involved the entire battle group during missile firing events. CSSQT could therefore set the stage for deployment, and provided insight into how the various ships might interoperate during tactical operations. At this stage, the Navy would use land-based testing to decide whether to purchase components for these new missile weapon systems, but for end-to-end system certification, at-sea tests was required.

4. AEGIS Weapon System Development

A principle design goal of the AEGIS Weapon System was to apply technology in such a way to build a new system far superior to that of currently fielded missile fire control systems. Weapon system complexity was a main challenge. In the earlier systems, computers had transitioned from analog to digital. The 1219 computer was limited to 64K Bytes. Computer programs for AEGIS were envisioned at millions of Bytes and the computer was completely different. The first AEGIS computer used was the AN/UYK-7 in a 4-bay configuration, bringing computing power never before realized to the missile fire control system. To properly test this new AEGIS system, new methods of ET&E,

from the element level, to the system level, would have to be pioneered – a lofty challenge that still, to this day, is evolving.

AEGIS integration and test was carried out at a number levels, closely monitored by the Navy's technical factory/manufacturer representative (TECHREP) at the various manufacturers that furnished AEGIS equipment components or assembled and tested AEGIS components.

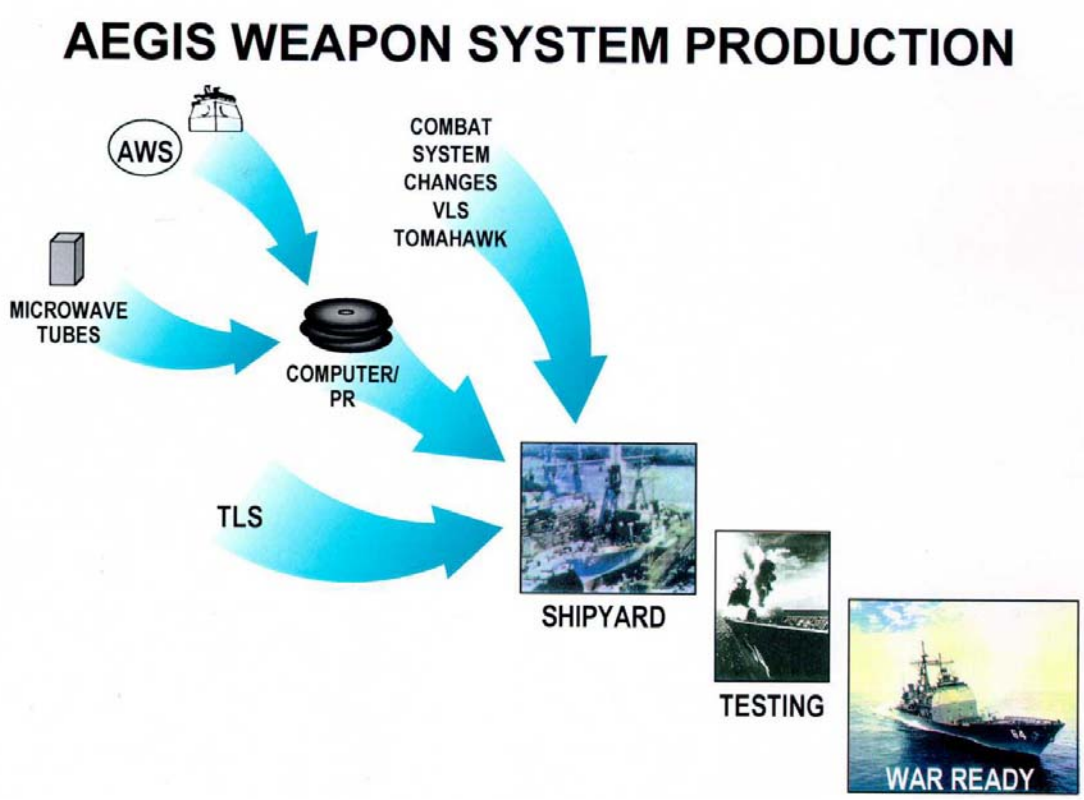

Figure 8. AEGIS Development & Testing (1983)

a) COMPONENTS - As specific pieces of the weapon system are being built, parts are constructed to DOD standards for manufacturing and reliability. Each component is tested once installed in the element piece.

b) ELEMENT PIECES - Each circuit card was tested before installation into its respective

cabinet. Cabinets, when assembled, were tested individually to weapon system specifications.

c) WEAPON SYSTEM COMPONENTS - Each weapon system component was assembled in a production test center (PTC) where integration and testing would be conducted at a "System Level" configuration. This testing was the basis for a level of performance that had to be duplicated at the shipyard for waterfront integration.

d) COMPUTER PROGRAM - Unlike previous missile fire control systems, computer program testing for AEGIS had to be started in a land-based environment, with interfaces being simulated. After initial land-based testing was completed, where the program was checked out in tactical hardware resident at the land-based test site, the program was then delivered to the PTC, where it was installed into the actual tactical equipment that would be delivered to a specific ship.

5. Land-Based Testing

Computer program integration has evolved with the technology. The difficulty in performance verification is compounded when these dramatically more complex systems (that these programs are designed to control have) vary in configuration from ship to ship. Upgraded components and configuration corrections in support of an ever-evolving system, although not by design, ensured that each ship would be unique. Even though the "ship class" held to standards of performance, each ship would find subtle, and sometimes not so subtle, variations that would need to be addressed through crew training and proficiency.

Land-based testing of the AEGIS computer program is currently conducted at several locations. The primary site for this testing was, and remains, the Combat System Engineering Development Site, (CSEDS), in Moorestown New

Jersey. This site was designed to house sufficient “end item” weapon system equipment to provide both system test and operator/crew training.

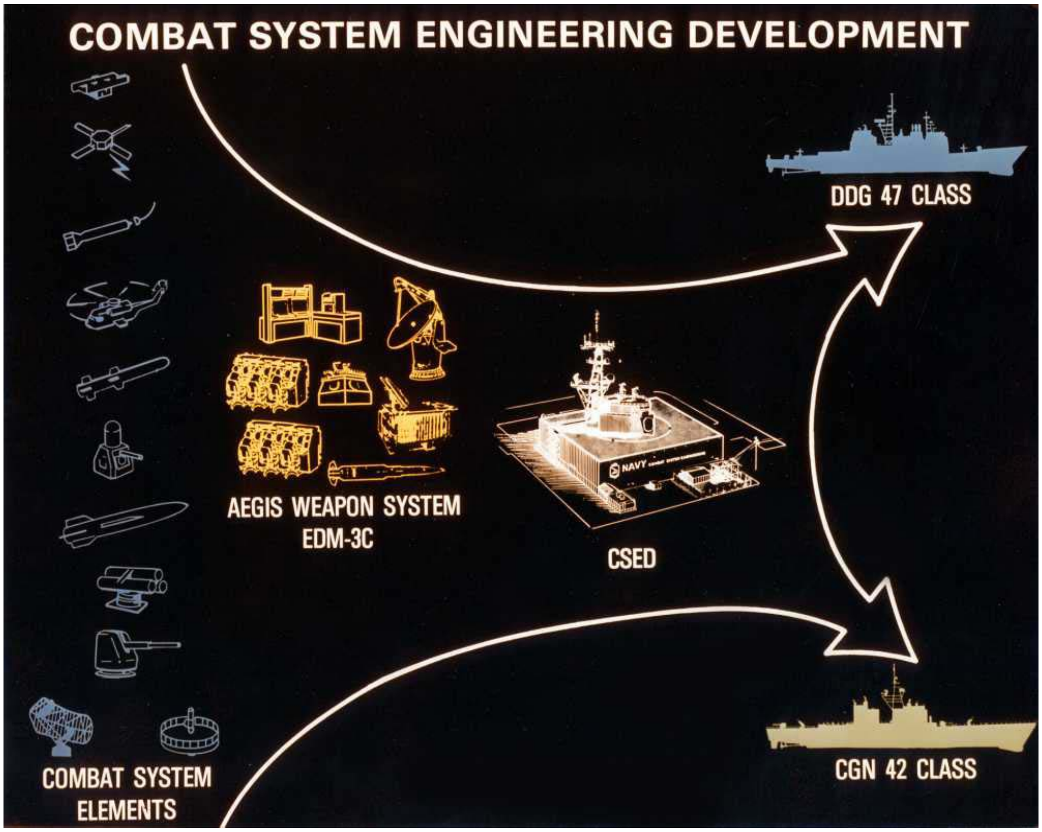

Figure 9. AEGIS Combat System LBTS Development (1977)

Another facility is the Production Test Center, located in Moorestown, New Jersey, where all of the individual components of the ships weapon system are assembled and tested, and computer program development and testing is executed. In the early stages of construction and “sell-off”, confidence in the capabilities of the system is traditionally high. The methodology for development and deployment of the first AEGIS system was to

"build a little, test a little," a paradigm that has remained consistent into current-day testing.

6. AEGIS At-Sea Testing

Proven through history, land-based testing is not, by itself, sufficient to certify performance. At-sea live fire testing is required. During development of the AEGIS Weapon System, at-sea testing was required before the system was released for production. After extensive Land-Based testing at CSEDS, a pre-production system was sent to the USS NORTON SOUND, a converted WWII seaplane tender, and became the home of the first AEGIS Weapon System. The system was installed and a massive test program was initiated. At-sea operations were conducted in stand-alone modes and also with other naval units when opportunities allowed. Multiple live fire events were conducted and AEGIS eventually proved to be a capable and flexible replacement for the already aged TARTAR, TERRIER, and TALOS systems.

After the release for production was given, the next phases of At-sea testing were completed during the new construction period at the shipyard. Prior to AEGIS, shipyard integration did not include a live missile-firing event. To this day, each AEGIS combatant is required to fire at least one missile during shipbuilder's trials prior to custody transfer of the ship to the Navy. Even in today's budget-conscious environment, builder's trials missile firings are mandatory for compliance to integration requirements.

The T&E community is continually challenged to demonstrate regression performance has been assured from

ship to ship, and baseline to baseline. Each ship, once constructed, must pass the same CSSQT requirements that previous systems have been required to satisfy. As the complexity of each follow-on AEGIS system has grown, so must the level of testing that is completed during each CSSQT.

AEGIS CSSQTs and live firing events have specific test objectives, with respective measures of performance that simply cannot be tested in a land-based environment and which often requires live ordnance to satisfy the objective. To ensure a high standard of testing is maintained, AEGIS test objectives are developed, approved, certified, and evaluated by the entire AEGIS technical community.

Over the last 23 years, thousands of AEGIS live fire test events have been completed at sea. The AEGIS community maintains a controlled closed loop engineering process that monitors system improvements and makes sure that ET&E events are at a level sufficient to adequately test the performance of the system. Whereas every AEGIS ship commissioned by the Navy is quantifiably unique, testing of specific measures of performance is required on each and every ship of the class.

7. Aegis in the Future

As the AEGIS Weapon System evolved, the ship classes, which carried the TARTAR, TERRIER, and TALOS systems, were decommissioned. These early missile systems led to the development of newer systems, including AEGIS, and pushed the limits of what T&E could provide. The latest versions of the AEGIS Weapon System continue to evolve, and so must

the state of testing and evaluation. As today’s threat evolves, so must future weapon systems. Testing, whether land-based, at-sea or via modeling and simulation, must continue until the last ship slips away and a newer ship takes on the roll of defender of the fleet.

D. TEST AND EVALUTATION – LOOKING FORWARD

The future of T&E should trace to the requirements and features of current and evolving threats, and in the designs and advanced concepts for future weapons and combat systems. For T&E to continue to provide the confidence and assurance in feasible, effective and suitable future systems, it must become more agile and more embedded in the process of acquisition. T&E consists of major and minor milestones across the acquisition timeline, which take time out, or away, from the program development. It is at these times that, ideally, the design must freeze, and in essence, a snapshot in time is of 80 taken in terms of performance and adequacy of design. Did we meet our specifications? Did we achieve expected tolerances? Did we get it right, in terms of where we are at along the development cycle? But in the future state percent solutions, and considering dramatically shrinking timelines, future T&E must be ingrained into the fabric of design and development.

Further, the premise of operational testing, including evolving operator needs, must be considered. The impact from the realization that suitability and effectiveness of design has not been met is lost if the system has already been delivered to the warfighter. The warfighter is

resolved, in fact trained, to make these systems work. Testing early, and rigorously under precise and controlled conditions is often a given. However also factoring in operational conditions is key towards ensuring the system under development is right for the mission.

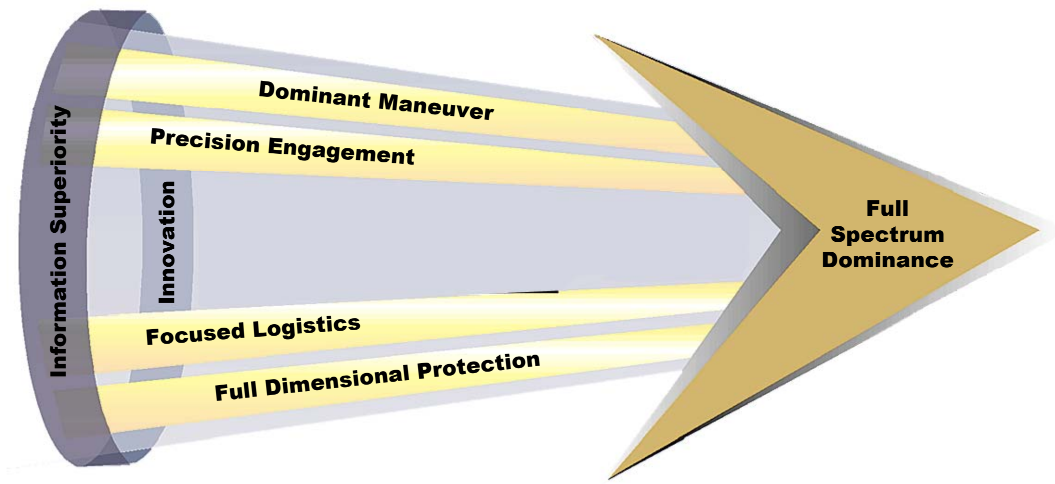

Figure 10. Joint Vision 2020

The Joint Chiefs of Staff recently built off the foundation established in Joint Vision 2010 and stated that Joint Vision 2020 should consist of dedicated individuals and innovative organizations transforming the joint force for the 21st Century to achieve full spectrum dominance to be persuasive in peace, decisive in war, and preeminent in any form of conflict. Several new areas were highlighted in JV 2020, including Joint Command and Control, interoperability, and Information Operations.

E. TEACHING T&E & COMMUNITIES OF PRACTICE

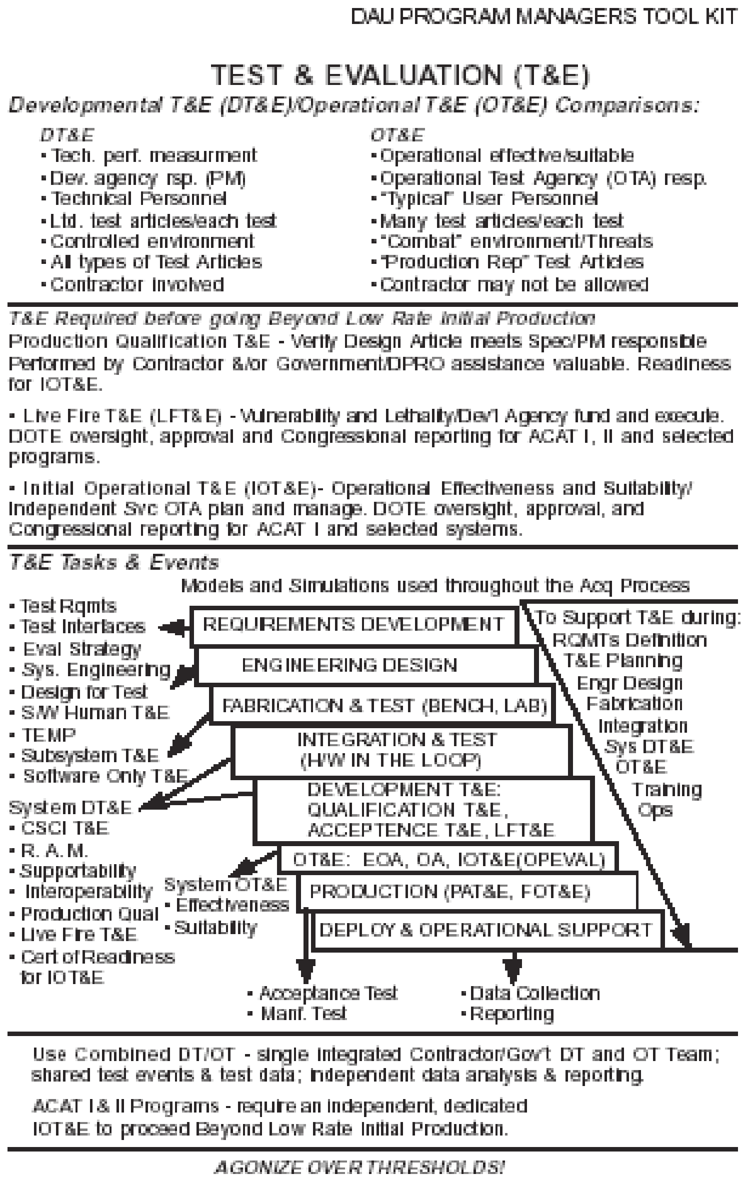

Figure 11. Program Managers Tool Kit – T&E (Version 13)

The Defense Acquisition University defines Test and Evaluation as a process by which a system or components provide information regarding risk and risk mitigation and empirical data to validate models and simulations. T&E

permit, an assessment of the attainment of technical performance, specifications and system maturity to

FY 1999 Notional Development Guide for the *Test and Evaluation* Career Field

Certification Levels		Level I	Level II	Level III		
Grade		GS-5 to GS-9 and O-1to O-3	GS-9 to GS-12 and O-3 to O-4	GS - 13 / O-4	GS-14 & 15 / O-5 & O-6	SES & Flag Officer
Career Category		Entry Level / Interns	Mid-Level	Acquisition Corps*	Critical Acquisition Positions	
Managerial/Leadership Development Goals *(LEI or equivalent administered at entry into the Acquisition Corps)*		Recommended Leadership Competencies Continual Learning Creativity and Innovation Flexibility Technical Credibility Written Communication Resilience Integrity/Honesty Accountability Interpersonal Skills Influencing/Negotiating Customer Service Decisiveness Problem Solving Oral Communication		Recommended Leadership Competencies External Awareness Service Motivation Strategic Thinking Political Savvy Partnering Conflict Management Team Building Financial Management Resources Management Cultural Awareness Entrepreneurship Technology Management Vision		
TRAINING	Mandatory Standards	ACQ 101 and TST 101	ACQ 201 and TST 202	TST 301		
TRAINING – Continuous Learning	Desired Standards	None	None	None		
TRAINING – Continuous Learning	Enhancements	• Level I Cross Training (e.g. SPORE), or, • Level II Certification Training • Training in appropriate leadership competencies	• Level I & II Cross Training, or, • Level III Certification Training • Assignment Specific training • DoD/ Federal Seminars addressing appropriate leadership competencies, e.g., DLAMP • Team Leader/Supervisory Training	• Team Leader Training • Supervisors: 40 hours Supervisory Training • Managers: 40 hours managerial training • Level I, II, III Cross Training • Courses and Seminars (government and private) which address appropriate leadership competencies, e.g., DLAMP • Federal Executive Institute (FEI)		• Govt, Univ, Institute and Prof Assoc courses and seminars addressing appropriate leader- ship competencies, e.g.,DLAMP • SES Courses • "Capstone," APEX Courses
EDUCATION	Mandatory Standards	BS/BA, with 24 semester hours in physical science, mathematics, engineering, chemistry, physics, ops research, or related fields; or 10 years of experience as of Oct 1, 1991.	Same as level I	Same as level I		
EDUCATION – Continuous Learning	Desired Standards	None	• Masters in physical science, mathematics, engineering, chemistry, physics, ops research, or related field. • Two 3 Continuing Education Unit (CEU) technical courses in a T&E specialty • Meet Acquisition Corps Education Requirements	• 12 semester hours from: accounting, bus. finance, law, contracts, purchasing, economics, industrial management, marketing, bus. qualitative methods, or organization and management • Masters as described at Level II (Desired) • One (additional) 3 Continuing Education Unit (CEU) technical course in a T&E specialty		
EDUCATION – Continuous Learning	Enhancements	• Begin 12 Semester Hours in Business • Continuing Education in Test and Eval fields • Begin Masters in Technical field or Business	• Complete Business courses • Continue Masters • Continuing Education technical courses • Professional certification	• Complete Masters • Level III education requirements in secondary career field. • Continuing Ed courses in related fields; DLAMP courses • Education or Training with Industry (EWI / TWI) • Intermediate or Senior PME (including SAC)		• Fellowships • Senior Acquisition Course or equivalent desired FY2002
EXPERIENCE	Mandatory Standards	One year of acquisition; T&E or technical experience preferred.	Two years in acquisition - one must be in test and evaluation	Four years in acquisition - two must be in test and evaluation		10 Years acquisition experience, of which 4 must be in a CAP
EXPERIENCE – Continuous Learning	Desired Standards	None	Two more years in acquisition - one must be in test and evaluation	Four more years in acquisition - two must be in test and evaluation		None
EXPERIENCE – Continuous Learning	Enhancements	• OJT and developmental assignments that address appropriate leadership competencies Internships providing exposure to other intra-organizational or functional settings	• OJT and developmental assignments that address appropriate leadership competencies • One 3-6 month assignment providing exposure to other intra-organizational or functional settings, e.g., DLAMP • Be on a team or serve as a team leader	• OJT and developmental assignments that address appropriate leadership competencies • 3-6 month assignment in a different organizational / functional setting, e.g., DLAMP • For selected members: • Broadening assignment, secondary career field. • Internship with Congress, Institutes, or an FFRDC • Broadening assignment, other technically oriented Federal agencies (e.g., NASA, NIST, etc.) • Assignment to manage two or more teams		SES sabbaticals and special assignments to complete experience in all leadership competencies

*NOTE: Criteria for selection into the Acquisition Corps include: (1) Four years acquisition experience; (2) A baccalaureate degree or certification by an ACPB; and (3a) At least 24 semester hours from among the following disciplines: Accounting, business finance, law, contracts, purchasing, economics, industrial management, marketing, quantitative methods, organization and management; or (3b) At least 24 semester credit hours in the individual's career field and 12 semester hours or equivalent training in the disciplines listed in 3a; or (3c) Pass an equivalency exam (See Appendix M for specific requirements for Acquisition Corps admission. Credit by examination is directed by 10 U.S.C. 1732 and covered in DoD Instruction 5000.58 (references (d) and (g)).

Table 1. T&E Career Field Developmental Guide (1999)

determine whether systems are operationally effective, suitable and survivable for intended use. Further, the definition goes on to describe two types of T&E – Developmental (DT&E) and Operational (OT&E). The latest release of the Program Managers Tool Kit has a helpful

diagram related to Test and Evaluation. This diagram compares and contrasts DT&E and OT&E, and provides a summary of production qualification T&E (sometimes referred to as PT&E), live fire T&E (LFT&E) and initial operational T&E (IOT&E). It also describes conditions when it might be prudent to combine DT and OT, and finally identifies the T&E requirements for ACAT I and ACAT II programs.

DAU maintains a curriculum to ensure T&E professionals are given the latest acquisition information. Career field developmental guides are available for each acquisition field, and break down paths for achieving certification within each respective acquisition profession, including training, education, and on-the-job experience. Similar to other acquisition career fields, T&E has three levels of proficiency, with suggested competencies for each.

COMOPTEVFOR OTDG lists a variety of helpful resources, including the Test and Evaluation Community Network (TECNET, 2003, n.p.), which is stated to include virtually every testing resource the OTD will need, including resources from the other U.S. military services or from civilian services, either nationally or internationally.

One of the responsibilities of the Deputy Director, Developmental Test and Evaluation OUSD (AT&L) is to ensure education and training of the T&E workforce, promote test & evaluation best practices, and to apply commercial practices to DOD programs.

The Defense Test and Evaluation Professional Institute (DTEPI) serves as the executive secretary to the T&E Functional Board for the Defense Acquisition Workforce Improvement Act (DAWIA). The Director, DTEPI also chairs

both the Focus Group and the Competency Working Group. The Focus Group is composed of T&E experts from across the career field who develop competencies, which are the basis of the Defense Acquisition University (DAU) courses that are required for DAWIA certification for the T&E functional component of the Acquisition Workforce. The Competency Working Group reviews the competencies developed by the Focus Group and assigns a learning level to each task.

DTEPI is chartered by the DOD Office of the Director, Operational Test and Evaluation (DOT&E). The primary purpose of the Institute is to provide career and professional development, education, training, and recognition for the T&E professionals supporting the DOD. The Institute also is to serve as a forum for enhancement of the test and evaluation process to meet current and future needs and challenges.

As part of the National Defense Authorization Act of 2003 creating the Defense Test Resource Management Center, section 234, the Under Secretary of Defense for Acquisition, Technology, and Logistics was requested to submit to Congress a report on the capabilities of the test and evaluation workforce of the Department of Defense. Working with the Under Secretary of Defense for Personnel and Readiness and the Director of Operational Test and Evaluation, the following was specified as requirements for a comprehensive plan:

> 1) The report shall contain a plan for taking the actions necessary to ensure that the test and evaluation workforce of the Department of Defense is of sufficient size and has the expertise necessary to timely and accurately identify issues of military suitability and

effectiveness of Department of Defense systems through testing of the systems.

2) The plan shall set forth objectives for the size, composition, and qualifications of the workforce, and shall specify the actions (including recruitment, retention, and training) and milestones for achieving the objectives.

The report needed to also include:

1) An assessment of the changing size and demographics of the test and evaluation workforce, including the impact of anticipated retirements among the most experienced personnel over the period of five fiscal years beginning with fiscal year 2003, together with a discussion of the management actions necessary to address the changes.

2) An assessment of the anticipated workloads and responsibilities of the test and evaluation workforce over the period of ten fiscal years beginning with fiscal year 2003, together with the number and qualifications of military and civilian personnel necessary to carry out such workloads and responsibilities.

3) The Under Secretary's specific plans for using the demonstration authority provided in section 4308 of the National Defense Authorization Act for Fiscal Year 1996 (Public Law 104-106; 10 U.S.C. 1701 note) and other special personnel management authorities of the Under Secretary to attract and retain qualified personnel in the test and evaluation workforce.

4) Any recommended legislation or additional special authority that the Under Secretary considers appropriate for facilitating the recruitment and retention of qualified personnel for the test and evaluation workforce.

5) Any other matters that are relevant to the capabilities of the test and evaluation workforce.

The OUSD (AT&L) response to this request was a report to Congress entitled, "Capabilities of the Test and Evaluation Workforce of the Department of Defense."

Component	OTAs	MRTFB	Other	Total
Army				
Military	494	41	73	608
Civilian	853	2,926	848	4,627
Total	1,347	2,967	921	5,235
Navy/USMC				
Military	272	1,310	30	1,612
Civilian	97	1,915	1,801	3,813
Total	369	3,225	1,831	5,425
Air Force				
Military	539	3,404	298	4,241
Civilian	200	3,647	93	3,940
Total	739	7,051	391	8,181
Defense Agency				
Military	5	81	29	115
Civilian	16	144	44	204
Total	21	225	73	319
Total, All Components				
Military	1,310	4,836	430	6,576
Civilian	1,166	8,632	2,786	12,584
Total	2,476	13,468	3,216	19,160

Table 2. DOD T&E Workforce by Component (2002)

F. T&E BEST PRACTICES

In a 2001 study sponsored by the Deputy Director, DT&E, OUSD (AT&L), conducted under contract by Science

Applications International Corporation (SIAC), a series of companies were visited to determine a set of commercial industry test and evaluation "Best Practices" that may have DOD test and evaluation organizational and process applicability. These best practices were grouped under two categories. Category I was defined as best practices that are either easily implemented or have already been partially implemented. Category II best practices were those less easy to implement and requiring examination by stakeholder teams to determine feasibility and to develop structure and schedules. The findings from this study follow. Starting with Category I:

Philosophy, Policy, Approach

1. Recognize that testing is a way to identify and solve problems early in the process in order to control time, cost, and schedule late in the process.
2. Recognize that best practices generate success and vice versa.

Test Investment

- Ensure early determination of the investment costs to acquire new capability for program support.
- Require analytically sound ROI analysis for test investments.
- Ensure cohesive (year-to-year) investment plans.

Test Execution

- Involve testers and evaluators very early:
    - Ensures testers know test requirements
    - Ensures developers know requirements for test
- Capture test costs at program initiation.
- Emphasize concurrent and integrated T&E.

- Institute formal quality check processes.
- Use System Integration Laboratories and embedded instrumentation.
- Give proper consideration to the use of external test capability in test planning.
- Ensure testers control test planning, equipment, facilities, instrumentation, and test resources.
- Continue to increase the use of modeling and simulation to expand the test process.

Test Evaluation

- Continue to increase the use of modeling and simulation to expand the evaluation context based on verified test data.

Category II:

Philosophy, Policy, Approach

- Stabilize corporate leadership and test staff.
- Focus on the quality of product and process to drive the efficiency and effectiveness of T&E.
- Develop consistent processes to ensure consistent products. Incorporate T&E as a process enabler.
- Increase T&E to assure product quality rather than reduce it to save T&E cost.
- Use metrics and quality control processes to understand how well the test process is operating.
- Implement efficient and effective test processes in order to compete. Keys:
    - Ensure T&E is consistently part of the decision, planning, and execution process.
    - Early commitment by all stakeholders on required T&E resources.
    - Certification of T&E processes and organizations (~ISO 9000)
    - Ensuring capital capability.

Test Investment

- Charge cost of test investment back to the program.

Test Execution

- Charge full cost of testing to the program.
- Emphasize multi-use T&E platforms.
- Do not generally support the outsourcing of testing and evaluation.
- Frequently use the Six Sigma or similar quality processes.
- Automate data collection and archiving.
- Benchmark in-house and within industry.
- Use measurements and metrics.
- Initiate programs to seek ten-fold reductions in the number of software tests required.
- Integrate Master Test Plans and test execution with program resources and milestones.
- Establish measures of effectiveness
- Quantify risk for management decision when considering reduced testing.
- Train the in-house test workforce in test engineering disciplines.

Test Evaluation

- Use Physics of Failure as a tool to predict and analyze system performance and shortfalls.
- Correlate faults and solutions in a closed loop process to ensure problems are resolved.

Test Philosophy/Process/Evaluation

- Establish corporate internal web based sites for exchange of ideas, benchmarks, data, applications, and processes. Address data collection retrieval, archiving, modeling and simulation, and test and evaluation methods.

The recommendations from this best practices study, as presented at the International Test and Evaluation Association in November of 2001 were:

- Implement or reinforce the Category I Best Practices in DOD as soon as possible.
- Develop implementation or reinforcement strategies for Category II Best Practices using DOD T&E stakeholder teams.
- Present the results of this study to the DOD acquisition and T&E communities.

III. OPEN SYSTEMS AND T&E

A. OPEN SYSTEMS VERSUS OPEN SOURCE

An Open System (OS) is a system that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability. An OS is characterized by the following:

- Well-defined, widely used, non-proprietary interfaces/protocols.
- Use of standards which are developed/adopted by industrially recognized standards bodies.
- Definition of all aspects of system interfaces to facilitate new or additional systems capabilities for a wide range of applications.
- Explicit provision for expansion or upgrading through the incorporation of additional or higher performance elements with minimal impact on the system.

(IEEE POSIX 1003.0/D15 as modified by the Tri-Service Open Systems Architecture Working Group, 2002.)

The open systems emphasis in improved interfaces and interoperability provides opportunity for superior performance, accelerated delivery, and more affordable systems. Open systems is an "enabler" for a number of acquisition reform initiatives such as cost as an independent variable, performance specifications, use of

commercial items, and configuration management (Open Systems Definition, 2003 ¶1.)

B. OPEN SYSTEMS AND STANDARDS

An open system design offers benefits such as life cycle support, affordability, and allowing timely technology insertion. However, there are substantial differences in the way open systems will have to be tested and evaluated. Whereas open system designs will rely on an increased use of commercial and non-developmental items in systems architectures, T&E will have to plan for significant technical differences. These differences will involve many aspects of engineering and management such as (DOD Open Systems Joint Task Force, 2003, ¶2):

- Standards-based architectures lessen the degree of control that DOD can expect to exert. Changes, fixes, and updates will likely be under the vendor’s control, but adherence to the standard can be expected.
- Standards-based elements of the architecture may be cheaper and faster to acquire but will not necessarily be cheaper and faster to integrate, update, test, and evaluate.
- Selection may be risky. Open systems acquisition will demand that the program manager know substantially more about technology and the associated conditions of various vendors.
- Standards evolve with time. While it is a challenge to visualize whether a given standard will endure, it may be more challenging to determine when to swap from one standard to another.
- Integration becomes more important than design. Performance requirements must be realized without explicit control of the component design specification.

- Once integrated, a component may impact global system parameters. Testing will become an on-going and continuing activity to verify that COTS and NDI items can be successfully integrated into future systems.

The following is defined in Volume 1.0 of the Navy's "DESIGN GUIDANCE FOR THE NAVY OPEN ARCHITECTURE COMPUTING CAPABILITY"(Strei, 2003, ¶1.3.3)

An open system approach has become an important aspect of system design and development in a wide variety of enterprises. This is true primarily because open systems convey certain benefits in terms of reduced life-cycle cost, reduced time-to-market, increased ability to inter-operate and cooperate with others, reduced personnel training, etc. A number of open systems definitions exist within the literature. This guidance document adopts the definition developed by the DOD Open Systems Joint Task Force (OSJTF), which operates at the level of the Office of the Secretary of Defense:

Open system: "A system that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style that facilitates portability." (DOD Open Systems Joint Task Force, 2003, ¶2):

Open systems – and architectures built to open system principles – possess a number of common characteristics. While not every open system possesses every possible characteristic, most open systems tend to possess most of

these characteristics. Based on examination of the various open system definitions, the attributes of an open system include the following:

- Use of public, consensus-based standards
- Adoption of standard interfaces
- Adoption of standard services (defined functions)
- Use of product types supported by multiple vendors
- Selection of stable vendor with broad customer base and large market share
- Interoperability, with minimal integration
- Ease of scalability and upgradability
- Portability of application(s)
- Portability of users

C. NAVY OPEN ARCHITECTURE

Navy Open Architecture (NOA) is an initiative to design and build a combat system that meets changing requirements into the 21st century, while also being rapidly and affordably upgraded throughout its life cycle (The Open Group, 2003). NOA plans to adapt and exploit new developments in open system design principles and system architectures, as well as standards-based computing technologies from the Commercial Off-The-Shelf (COTS) marketplace.

The NOA Working Group plans to first develop a coordinated open architecture for real-time and embedded system environments that would be mutually beneficial for various architecture approaches to include but not limited to: DOD Joint Integrated Open Architectures, Navy Open Architecture, Air Force Viable Combat Aircraft Joint

Council on Aging Avionics, Modular Open Systems Approach Interoperability Initiative, Army Weapon Systems Common Operating Environment and various open architectures from corporations and system integrators.

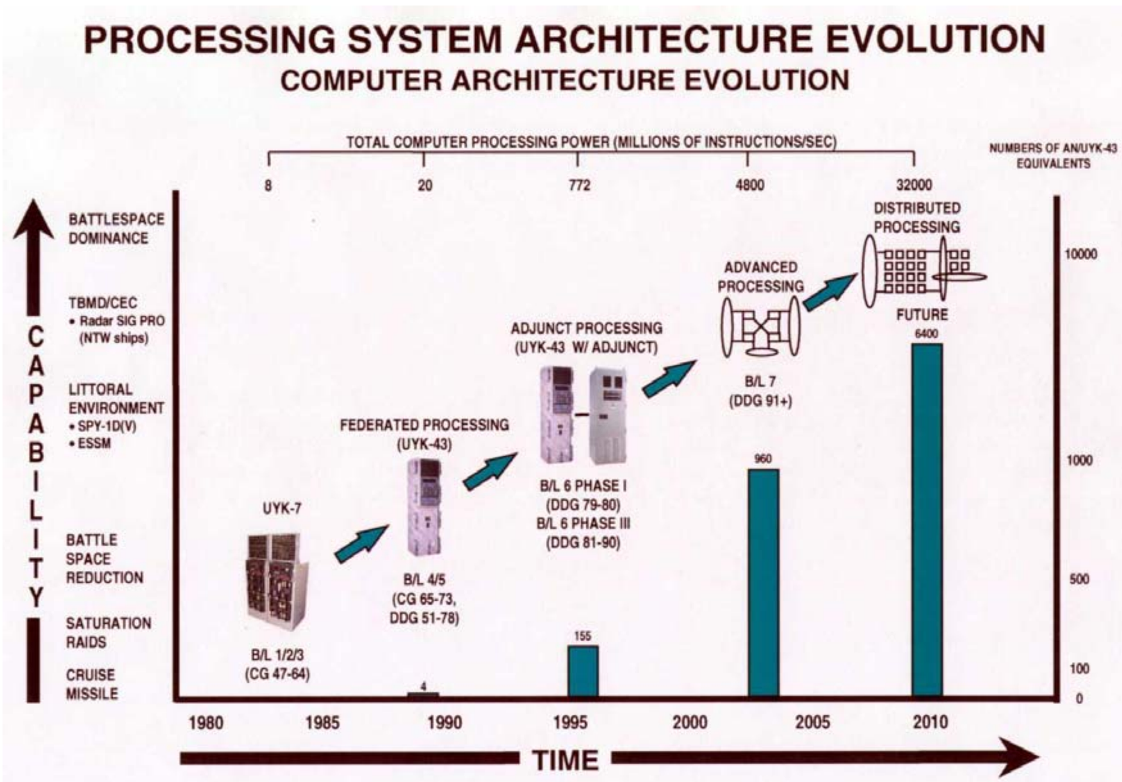

Figure 12. Computer Processing Architecture Evolution

This approach would leverage the information technology industry investment in the development of COTS components. The use of COTS should allow for easy transition to commercially available advanced hardware and software technology. The key to this approach however, is the use of COTS products that already use open standards. Open standards promote conformance at the interface level ensuring compatibility and interoperability. Development

of a fully open architecture would allow for the use of future technology and transition the insertion of components from one generation to the next based on hardware and software products that are conformant to open standards (Chief Information Office, The Open Group, 2003.)

The Navy gradually wants to do away with decades-old proprietary combat-system software and replace it with a modern open architecture (Erwin, 2003, ¶1.) The cost to move MILSPEC, Navy-specific systems into commercial computing environments is difficult to calculate, but could save billions of dollars, over time. And an open architecture could help the Navy improve the capabilities of the AEGIS combat system for future missile-defense missions.

> An open architecture is what technologists call a “plug and play” computing environment, one that allows for easy upgrades of software applications, without having to reengineer a warship’s entire combat system. “The analogy is that when you get a new refrigerator, you don’t need to worry about testing the sink and everything else,” said one industry expert (Erwin, 2003, ¶2.)

Whereas the Navy already spends billions of dollars annually upgrading proprietary software, an open architecture is seen as the path to significant savings.

> There is undoubtedly a technological incentive surrounding open architecture. While pushing forward in such pursuits, the Navy must simultaneously provide new combat-system computers, while keeping the AEGIS fleet ready for war and meeting its missile-defense commitments. By 2005, the Navy is expected to deploy 18 anti-ballistic missile AEGIS warships—three cruisers and 15 destroyers (Erwin, 2003, ¶3.)

In charge of developing a plan to introduce open-architecture computers in the Navy by 2010 is a new organization created last year, the Program Executive Office for Integrated Warfare Systems (PEO IWS). PEO IWS is working with large and small companies to develop standards and protocols that will eventually influence every computer system in the Navy.

> Open architecture is "the right way to go" for the Navy, said Rear Adm. C. Tom Bush, the head of PEO IWS. "We need to stop building proprietary architectures." Bush believes that an open architecture can help make those upgrades easier and less costly, saving the Navy at least $1 billion a year (about 50 percent of the service's annual expenditures on software upgrades). "On a good day, when something needs an upgrade, it requires seven to 28 changes," Bush said. "We can't build a combat system for every ship. But we can build a single architecture." (Erwin, 2003, ¶5-7.)
>
> Another benefit of open architecture is "interoperability," said Rear Adm. Henry G. Ulrich III, director of Naval Surface Warfare. "The business model and the architecture we have now are driving us away from interoperability, not only with our allies but amongst ourselves. ... The current technology, which is not compatible with anything else, drives up the cost of producing and upgrading software."
>
> The Navy's director of open architecture is Tom Pendergraft, a career combat-system engineer. Upon taking the job only a few months ago, he quickly learned that bringing open architecture to the Navy is less about technology and engineering than about "culture and business models changing," he said in an interview. The enormous expense associated with software upgrades and a desire to improve the current technology make it imperative for the Navy to begin migrating to open architecture, he said. Upgrading the AEGIS combat system on average can

> cost hundreds of millions of dollars. Not only can the service not afford these prices, but in many cases, the computers have been upgraded so much already that their capacity to grow has been exhausted. "Necessity is the mother of invention," Pendergraft said. "That is what we are talking about here."

At the center of the Navy's theater defense capability is the AEGIS Weapon System. With a phased-array radar that can track hundreds of targets simultaneously, and a command and control computer system allowing simultaneous tracking operations in air, surface and undersea warfare, keeping pace with the emerging threat is critical. Detect, track and engage functions require enormous computing capability, with millions of actions being performed by the host weapon system every second.

> In the early days of AEGIS, said Pendergraft, "we had a single computer that did all the computation for warfare systems." As the operations became more complex, when the Navy started using more advanced weapons, the computing power needs grew exponentially. Another drawback to the current technology is that it is "serial," meaning it can do one thing at a time - detection, tracking, identification, decision, engagement. "You only had one computer to do all that. ... Our architecture is serially based, with point-to-point connectivity," said Pendergraft. "Pretty soon, you have what we call spaghetti code." (Erwin, 2003, ¶9.)

This "spaghetti code" is commonly the reason why upgrades are so expensive. Besides the fact that this legacy code can only be maintained by a shrinking resource pool, when a single applications is upgraded, whether to fix a software bug, or to build in more capability, the entire weapon system has to be tested to make sure no changes were made inadvertently to other functions.

> “Today, when we make a change, by the nature of the shared-memory architecture, you end up having to retouch the entire system,” said Orlando Carvalho, vice president of AEGIS programs at Lockheed Martin Corp. “In some cases, you have to make many changes for a fairly small upgrade.” Norm Malnak, Lockheed Martin technical director, said the problem is exacerbated by the presence of multiple AEGIS baselines (software releases) throughout the fleet. The oldest ships, for example, use baseline 1.4. Others have baselines 2.1, 5.3 or 6.3, for the newest ships. Lockheed Martin is developing baseline 7.1, with more advanced features. An open architecture will help “get commonality across the fleet,” said Malnak. “That saves a lot of money.” (Erwin, 2003, ¶11.)
>
> The Navy has spent hundreds of millions of dollars on modern computers to expand the memory and computer processing speed of AEGIS combat applications, but fast PCs is not what open architecture is about, explained Pendergraft. “We went to COTS computers, but we haven’t done anything with all the point-to-point connectivity. ... With open architecture, we are changing the fundamental structure.”

Navy Standard Computers are used to process the input and output data. AEGIS uses several variants of the AN/UYQ-43 computer, but each lacks the speed and memory of personal computers found commonly in the office or in the home. The Navy has increased computing power through the use of adjunct processors and additional memory, but the UYQ-43 handles the critical functionality that eventually builds fire control solutions, leading to ordnance on target.

> “Our current Navy Standard Computers are at about 99 percent capacity,” said Pendergraft. “Every time we want to add a new function, we can’t do it on NSC, so we add adjunct computers.” This setup still maintains the “spaghetti code”

> structure. By adding more processors and functions, "all the stuff starts crisscrossing. We have point-to-point spaghetti code all over the place. It makes it very complicated and expensive to maintain." Further, "we are prohibited right now from adding a lot of significant war-fighting capability, because we don't have the computing capacity," he said.
>
> To make the open architecture plan work, "we have to stop people from putting proprietary computers on ships. That is what kills us. Every time there is an upgrade or the manufacturer goes out of business, we are toast. We have to hire someone to rebuild that system, or we have to keep someone in business for a lot longer than we want to." Unfortunately, he said, "There is no police force for specs and standards." (Erwin, 2003, ¶13.)

Open architecture requires a significant up-front investment and questions about its claimed merits. PEO has provided various estimates of what it would cost to convert the entire fleet, but the debate over legacy development versus open systems development seems to be winding down.

D. OPEN SYSTEMS AND MDA

As the Navy moves closer to fielding a ballistic-missile defense for the United States, the ability of computers to do the job comes into question. Even in the most modern of deployed weapon systems, the computing environment is taxed to the point that further enhancement or upgrades may not be possible. According to PEO IWS's OA lead, Tom Pendergraft, "current computing plants are pretty full. If you want to add BMD on top of that, that is going to be pretty tough. ... If we go to open architecture, with distributed computing, we would have virtually unlimited [computational power] resources." (Erwin, 2003, ¶17.)

> It is possible to accomplish missile-defense missions in legacy AEGIS ships, "assuming some modifications to open up the architecture," he said. "You are not going to get there with one computer."
>
> Future missile-defense capabilities the Pentagon envisions, such as new solid-state radar and extended range weapons, will require more computing power than currently exists. "As you move forward with missile defense, you want additional signal processing capability," said Chris Myers, director of missile defense and radar programs at Lockheed Martin. The company is responsible for various pieces of the naval missile-defense program, including AEGIS, cruiser upgrades, and the development of an active solid-state radar.
>
> We want to upgrade those computing plants so it makes it a lot easier to upgrade AEGIS," said Myers. "In the future, you want to see targets further away, smaller things, you need additional radar power and sensitivity to see that. ... There is additional computing power required as you move to a solid-state radar. (Erwin, 2003, ¶19.)
>
> Lockheed is one of 49 companies that received contracts to help the Navy come up with commercial standards and protocols for the open architecture. The plan is to begin installing the new technology on surface ships and then expand to submarines. The DDX land-attack destroyer, to be deployed by 2012, is expected to be the Navy's first truly "open-systems" ship.

In March, PEO IWS released an interim set of specifications and standards that new programs will have to follow, in order to be open-architecture compliant. Existing legacy systems however, will have to be addressed as well, but there are challenges. Existing weapons systems using dated technology require very specific techniques and talents to upgrade, which will likely be very expensive. In addition, DON continues to train and fight wars with ships

that cannot afford to be taken out of service for the time it would take to complete a comprehensive upgrade, let alone test and evaluate. Moving into OA standards allows future systems to evolve, but will also allow existing systems to eventually become more open.

> A transition to open architecture, for example, would involve "taking pieces of our combat systems, throwing away the old code, rack and stack the algorithms, write them in modern computing program so they can run on a modern computing environment," said Pendergraft. "In the AEGIS program, we are starting now to open up the system," he said.
>
> Rick Scharadin, program manager at Lockheed Martin, said the company will demonstrate how segments of AEGIS can be converted to open architecture in a piecemeal fashion. The first step is to upgrade the computing environment for the radar, by 2006. The second piece is to convert the displays, by 2007. In 2008, the plan is to demonstrate open-architecture radar and displays, weapons control and fire control. "The key is to find those parts that you could easily remove," said Pendergraft. "The only way we'll be able to do this is one part at a time. Can't do it all at once." (Erwin, 2003, ¶13-21.)
>
> PEO IWS plans to spend about $50 million a year on research related to open architecture. A lot more money, however, will be needed to upgrade ships. Those funds may have to come from ongoing acquisition programs, a prospect that Pendergraft acknowledged will stir the proverbial "rice bowls" associated with military projects. "Some of the programs of record are going to have to change direction in order to pay for this," said Pendergraft.
>
> "In a front-line combat system like AEGIS, you cannot do plug and play without doing specific reengineering to make sure you haven't contaminated the system integrity," said retired Rear Adm. George Meinig, who was the AEGIS technical director in the mid-1980s. "The

> benefits of open architecture are still desirable," he said. "But there is no assurance that unaltered commercial products can meet the performance requirements of the combat system. ... You have to do careful testing to make sure the design is compliant with the requirement and that you haven't messed up the whole system." (Erwin, 2003, ¶25.)

As the benefits from employing open architectures are becoming more well understood, the return on investment might not be seen for many years. And the initial conversion to an OA would not necessarily increase the capability right away, but instead allow for the potential growth in the future. So as current, in-service weapon systems are on the verge of obsolescence, open systems architecture could, in concept, give them the ability to serve the warfighter into the future.

According to some very recent educational forums sponsored by DAU and focused on Program Management looking towards the future, open architecture can be summarized with the following aspects:

- Today's Fleet computing architectures are performance limited and expensive to upgrade.
- Implementation of warfighting functions using standards-based solutions will enable common, interoperable capabilities to be fielded faster at reduced cost.
- Rapid Technology Insertion Program (RTIP) will provide a structured approach for introduction of OA components into the Fleet (Program Managers Workshop, 2003.)

E. NOA – EMERGING GUIDANCE

From Version 1.0 of DESIGN GUIDANCE FOR THE NAVY OPEN ARCHITECTURE COMPUTING CAPABILITY, Navy open architecture is the high-level technical structure of the weapon system

as designed in accordance with the principles of open systems to achieve both real-time mission requirements and life-cycle supportability goals. Technical characteristics of NOA include:

- Distribution of processing
- Widespread use of standards-based COTS computing technologies
- Functional capabilities implemented as medium-grain components
- Use of object oriented (OO) programming within components and middleware technologies for interconnection of and interoperation among components
- Use of design mechanisms such as client-server to maximize isolation of implementation details from publicly visible services and APIs
- Portability and transparency of application components with respect to physical location and network, processor and operating system types, etc.

The corresponding goals of the NOA are to provide to the weapon system not only the benefits of assured technical performance, but also of reduced life-cycle cost, affordable technology refresh, and reduced upgrade cycle time. Expected benefits include:

- Scalable, load invariant performance
- Enhanced information access and interoperability
- Enhanced system flexibility for accomplishment of mission and operational objectives
- Enhanced survivability and availability

- Reduced life-cycle cost and affordable COTS technology refresh
- Reduced cycle time for changes and upgrades.

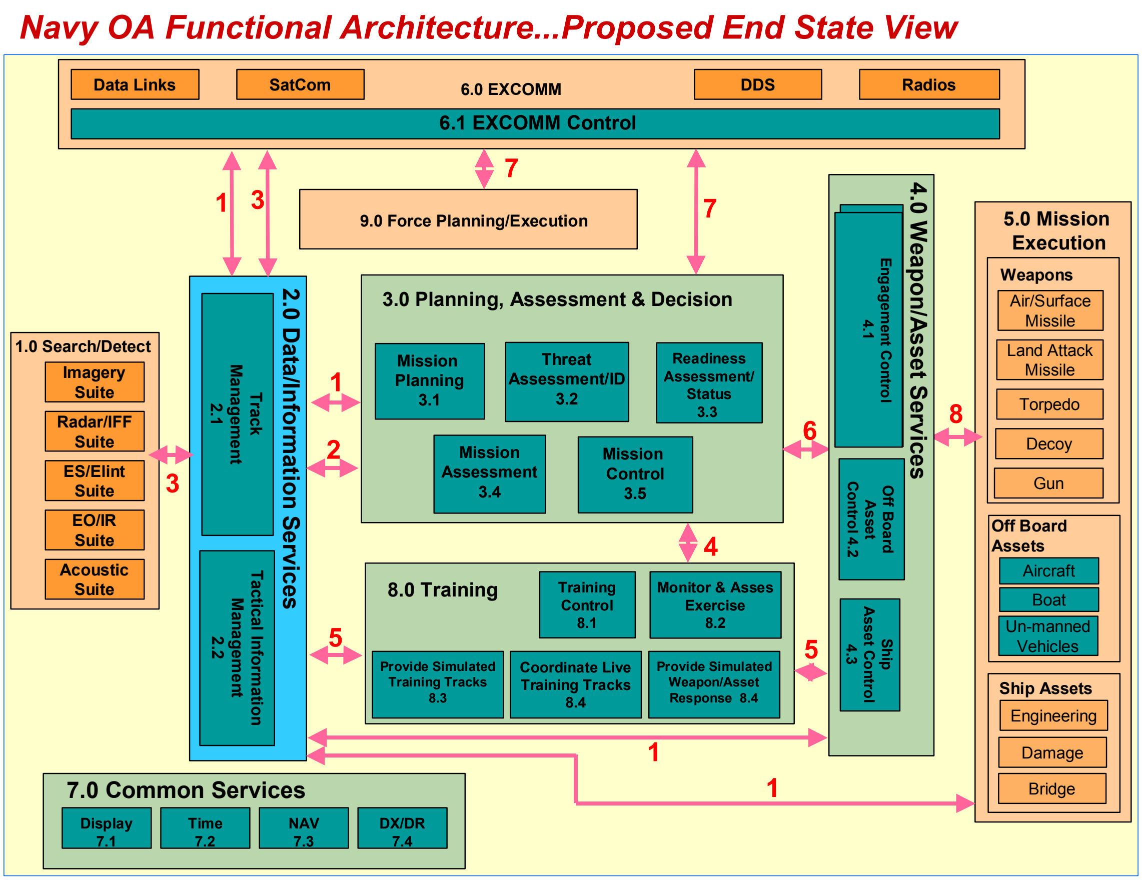

Figure 13. Notional NOA Functional Architecture

F. NOA GOALS AND FUNCTIONAL ARCHITECTURE

In broad and general terms (Strei, 2002), architecture is defined as "the structural design of an entity." Adding "openness" to the list of architectural characteristics implies that the "structure" of the architecture explicitly promotes interoperability, both internally and externally, as well as ease of modification and extension.

It is an engineering truism that what is achievable in system design (architecture) is a function of not only the task to be accomplished but also the technologies that are available. However, the evolution of high performance COTS, combined with continued growth of weapon system and combat system requirements, provides an opportunity to design an architecture more capable of exploiting new technologies than the federated legacy architecture that has served the Navy for well over two decades. The need for evolution toward an open architecture is motivated by both performance and supportability considerations. Commensurate with this dual set of motivating factors, the goals of the NOA are as follows:

- Combat system, weapon system, command support system and HM&E capabilities that continue to pace the threat.
- System design that fosters affordable development and life-cycle maintenance.
- System design that reduces upgrade cycle time and time-to-deployment for new features.
- Architecture that is technology refreshable despite rapid COTS obsolescence.
- Improvements in NWS Human Systems Integration.

Finally, system requirements may include not only capability and performance goals but also non-functional engineering goals as well ("-ilities"). In addition to traditional metrics such as reliability and survivability, NOA metrics include qualitative goals such as portability, scalability, extensibility, and flexibility of use. These goals will be met, in part, by careful design and in part through use of open systems principles and standards. This document focuses primarily on the technical aspects of designing NOA. However, in many cases, the recommended design choices and technologies are chosen with the goal of supporting this qualitative metrics as well.

G. WHY OPEN ARCHITECTURE?

In a recent Defense News article discussing the U.S. Navy's decision to change its acquisition strategy for CEC, replacing a winner-take-all approach with a series of smaller competitions, the rationale was OA.

> "We're totally changing the plans for CEC Block 2," said a Navy official. Instead of a closed system, Block 2 will incorporate open-architecture standards to hold costs down, allow more joint interactions, and help the fleet to adapt more quickly to new threats. Service officials hope this new approach will encourage innovation, entice more firms to compete for the work, and ultimately push down purchase costs (Sherman, p.1, 2003.)

Open architecture is the key to affordable 21st Century joint combat capability (Program Managers Workshop, 2003.) OA enables current weapon systems, and corresponding computing systems, which today cannot support emerging Sea Power 21 warfighting capability requirements, to be upgradeable to meet these future needs. In addition, OA is claimed to be affordable, although this is a subject of great debate at present. What is not debatable is that current, in-service computing architectures are unaffordable. Presently, each ship class addresses common problems uniquely, while software and hardware changes are interdependent. Finally, OA must support Joint Interoperability. Today's existing in-service architectures cannot support Forcenet implementation.

The OA implementation strategy must include several concepts. To begin with, computer program upgrades that provide only marginal warfighting capability enhancement must be frozen and future upgrade plans terminated. OA

technical and functional architectures must be completed and consensus gained for scaleable, Navy-wide applications. A Rapid Technology Insertion Program process has been proposed to transition promising technologies to certified warfighting products. All new systems must comply with agreed-upon and documented OA standards specifications and guidance. Finally, proponents of open architecture should pursue coordination and agreements with all other initiatives and programs.

IV. T&E IN THE FUTURE

A. INDICATORS

In an Inside the Navy article dated September 8 2003, entitled, "Study prepared for Young: Cohen predicts Navy will put EM gun on DD(X) within a decade," The navy plans to have an electromagnetic rail gun aboard a DD(X) destroyer in eight to 10 years, according to Chief of Naval Research Rear Admiral Jay Cohen, who expects the total cost of developing one or two gun prototypes would be $500 million to $1 billion. Though not explosive, EM gun projectiles would hit targets with uncanny speed and devastating force, setting a new standard for deadly, long-range shipboard guns. "I will tell you, we think in eight to 10 years, you're going to see a 250-to-300 mile electromagnetic rail gun on DD(X)," Cohen predicted in a presentation at "COMDEF 2003" in Washington, DC.

"We must acknowledge that our way of war requires superiority in all mediums of conflict, including space. Thus, we must plan for and execute to win space superiority."

Gen. Richard B. Myer, Vice-Chairman, U.S. Joint Chiefs of Staff

"The idea of putting weapons in space to dominate the globe is simply not compatable with who we are and what we represent as Americans."

Figure 14. From NMD: The Arctic Dimension (2003)

While there is plenty of speculation and high hopes for future systems to be developed and acquired in the future, but there is very little evidence of how we might prepare to test and evaluate these emerging systems. In

addition, there appears to be no consensus about what testing in the future will look like.

B. HOW DOES OPEN SYSTEMS ARCHITECTURE CHANGE THINGS?

In a speech by RADM Phillip M. Balisle, Director, Surface Warfare Division (N76) to the Surface Navy Association (March 2002) he stated, "As we explore the transformation of the existing AEGIS baselines into an open architecture, distributed processing combat system, we intend to build these interoperability enhancements into our new systems from the ground up." He continued by saying, "Following the successful transition to a complete COTS computing environment on our new construction AEGIS DDGs, AEGIS baseline development will introduce an open architecture, high performance, interoperable and network ready software architecture, which will eliminate many of the interoperability limitations of today's combat systems." He concluded his speech by stating, "When we align our systems and integrate them using a systems engineering approach into a new architecture which allows for the efficient exchange of required data across the network, we will realize another dramatic increase in situational awareness, speed of command and synchronization that will buy back even more critical battle space for our Warfighters."

C. T&E IN THE MISSILE DEFENSE AGENCY

The Missile Defense Agency, in July 2003, released the following information regarding test and evaluation (BMD Test & Evaluation, 2003, pp. 1-2.):

> The Ballistic Missile Defense (BMD) test philosophy recognizes the need for an integrated,

phased test program that comprehensively covers all facets of testing. Testing components, subsystems and systems, especially early in the developmental cycle, can determine current performance capabilities and identify potential design areas where technology can increase overall system capability. Later testing demonstrates and measures the effectiveness and suitability of missile defense systems in their intended operational environments.

The BMD System (BMDS) test methodology adds system complexities over time. For example, system performance in the presence of countermeasures and operations in increasingly stressful combat scenarios would be addressed in segmental tests. This step-by-step approach facilitates timely assessments of the most critical design risk areas.

The MDA test and assessment program supports credible decisions with respect to the BMDS and its elements. Specific program objectives focus on: characterizing, demonstrating, measuring and verifying achievement of BMDS capabilities; executing BMDS test events; facilitating credible testing of BMDS Elements, technology experiments and international collaborative programs; and anchoring Modeling and Simulation with test data for use in measuring performance throughout the test envelope.

Meeting the challenges of BMD testing requires an extensive test infrastructure. Collectively, groundtest facilities, ranges, sensors and instrumentation assets provide valuable BMD program-wide risk reduction and test capability to assess BMD system and element performance. Ground tests are conducted at high-speed sled tracks, hardware-in-the-loop facilities, aero-ballistic ranges, aero-optic and aero-thermal shock tunnels and space chambers.

MDA deploys mobile airborne sensors to ranges during flight tests, which have onboard signal and data processing and collection capabilities. More recently this includes the development of transportable instrumentation and

common standards to support MDA testing with flexible scenarios at a variety of locations.

MDA conducts BMDS Integrated Tests using selected hardware and software from the individual elements to investigate performance, joint operations and interoperability. These tests include the Critical Measurements Programs and the System Integration Tests. The former are live test flights that provide common data collection opportunities and the latter are live intercept tests involving representations of potential future threats. Results of all tests are used to conduct annual system- wide capability assessments.

D. THE FATE OF OT – ONE EXAMPLE: MDA

The Bush administration is proposing to exempt the Pentagon's controversial missile defense system from operational testing legally required of every new weapons system in order to deploy it by 2004 (Schrader, 2003, p.1.)

In the FY 2004 budget, is a request to rewrite a law designed to prevent the production and fielding of weapons systems that don't work. If the provision is enacted, it would be the first time a major weapons system was formally exempted from the testing requirement. The proposal follows administration moves to bypass congressional reporting and oversight requirements in order to accelerate development of a national missile defense system. One of Bush's goals when he took office was to carry out a missile defense system — an idea first proposed by President Reagan — and he almost immediately expanded the scope and the funding of the controversial program, which had encountered scientific and budgetary difficulties in recent years.

Last year, to help achieve that goal, Defense Secretary Donald H. Rumsfeld gave the Missile Defense Agency unprecedented managerial autonomy and removed procurement procedures that

were intended to ensure new weapons programs remain on track and within budget (Schrader, 2003, p.2.)

While the exemptions granted previously gave the missile defense program an unprecedented degree of autonomy from congressional oversight, they did not exclude it from testing. Highlighting its technical weaknesses has been opponents' best hope for slowing the long-debated program. In recent years, critics repeatedly have used Pentagon data from missile defense flight tests to challenge whether the experiments were as successful as claimed.

The latest proposal from the Pentagon would exempt the missile defense deployment from a law that requires the Defense Department to certify that appropriate operational testing has been completed before putting systems into production.

The Bush administration announced in December 2002 a goal of having a limited ground-based system operational in Alaska and at Vandenberg Air Force Base in California by Oct. 1, 2004 (Schrader, 2003, p.3.) "The moves last year were just about reporting requirements. This is different," said Philip Coyle, director of operational testing and evaluation for the Pentagon from 1994 to 2001. "This is about obeying the law. Without these tests, we may never know whether this system works or not, and if they are done after this system is deployed, we won't know until we've spent $70 billion on a ground-based missile defense system."

In a letter to Rumsfeld, Feinstein wrote: "I believe that any deployed missile defense system must meet the same requirements and standards that we set for all other fully operational weapons systems. Indeed, given the potential cost of a failure of missile defense, I believe that, if anything, it should be required to meet more stringent test standards than normally required."

Rumsfeld replied that an exemption made sense in the case of missile defense (Schrader, 2003, p.4.) "I happen to think that thinking we

cannot deploy something ... until you have everything perfect, every 'i' dotted and every 't' crossed, it's probably not a good idea," he said. "In the case of missile defense, I think we need to get something out there, in the ground, at sea, and in a way that we can test it, we can look at it, we can develop it, we can evolve it, and ... learn from the experimentation with it."

Rumsfeld pointed out that two other weapon systems in recent years — the Predator unmanned aerial vehicle and the Joint-STAR aircraft radar systems — were deployed before they were tested operationally. But those systems did eventually go through operational testing, and neither went into full production until the testing was completed. There is no guarantee the operational testing will ever take place if the law is changed to allow the system to be deployed (Schrader, 2003, p.5.)

E. WHERE MODERN T&E MUST EVOLVE

To meet the challenges presented by an evolutionary acquisition, and a US Navy deep into transformation, requires a T&E methodology that is equally as transformational.

The Navy is actively engaged in the acquisition of future, technology-exploiting weapon systems. In a recent article (Schweizer, 2003, p.5) discussing the merits of directed energy weapons, "Navy officials admit there's plenty of hard work ranging from basic science to rigorous operational evaluation - to be done before some of these systems sail aboard a warship. Even so, it's a generation of weapons that is tantalizingly close to becoming reality." The good news is that someone is giving some thought to the issue of evaluation, meaning that the notion

of test and evaluation is not lost in the active pursuit of a desirable new technology and corresponding weapon system which will certainly bend the envelop for testing at our present ranges, and using our present targets. In addition, during the month of October 2003, ITEA will be conducting a symposium on understanding direct energy, with implications towards T&E. Perhaps the T&E community of practice is already on the right path.

F. AEGIS T&E – LOOKING FORWARD

The AEGIS T&E Process has always been intended to be a universal process, with applicability to both government and contractor personnel in all phases of the acquisition cycle, developmental, operational, or combined. Its use implements a "Build a little Test a little" philosophy and stresses testing before expending ordinance.

Discipline in this test process is recognized as a contributor to cost effective system acquisitions that satisfy the Navy's needs. A disciplined and well-structured test program reduces the risk of acquiring an ineffective system and provides the program manager with timely information required to make prudent decisions during system development.

Testing ranges from early component testing at the factory, to full system live fire performance demonstrations in a simulated real world environment. Regardless of the type of test, there are five guiding principles to help ensure the system under test fulfills its intended purpose.

1. Develop meaningful and applicable test objectives, and adhere to them in an orderly, repeatable, and disciplined manner.

2. Use the closed loop systems engineering approach, from concept, to component, to subassembly, to subsystem, to system, to whole ship test.

3. Test as early as possible and as often as affordable to find and correct problems before they become too costly.

4. Involve the user, developmental tester and operational tester in the initial formation of the systems engineering council to develop test objectives to ensure continuous and timely information exchange of objectives and test results.

5. Take the time to ensure all parties (developer, contractor, and government operational testers) thoroughly understand the systems mission requirements and agree on how the system will be tested, scored and evaluated.

The need to take a disciplined approach in AEGIS T&E has been demonstrated many times in the past. Risks must be understood and controlled. Once a latent deficiency manifests itself, it is no longer a risk; it is a problem. The AEGIS Test and Evaluation community is an essential means of identifying, understanding, addressing system issues within both hardware and software.

To evolve in the future, AEGIS T&E will complete five objectives for each improvement, modification, or system mission change:

1. Verify that test results are credible and support system acquisition milestones for decision-making. Incorporation of an OA software implementation system performance should be the same if not better then the previous legacy system.

2. Provide early identification of AEGIS performance and supportability deficiencies for resolution. When limitations are discovered, they must be addressed as soon as possible to support further tests of performance.

3. Identify and measure performance parameters that are critical to operational effectiveness and suitability through rigorous analysis and evaluation during the evolution of system requirements.

4. Provide early identification and timely acquisition of test resources and assets necessary to stress the system. T&E assets are required to meet the approved test objectives and provide a means to verify specification compliance.

5. Execute test programs that consistently apply the closed loop systems engineering approach to T&E.

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V. CONCLUSION

A. RECOMMENDATIONS

The Navy has invested billions of dollars into weapon systems that are increasingly complex and are still evolving. Changes to computer program architecture and introduction of COTS equipment illustrates the Navy's requirement to improve existing systems and hulls. With this evolution T&E culture must also evolve to support future weapon systems that are increasingly complex and agile. It is not possible to proceed forward doing business the way it has been done in the past. Change in configuration forces the evolution of T&E. To evolve with the systems the T&E community must be vigilant in the following areas:

<u>Agility</u> – To be adaptive to evolving threats, increasingly complex weapon systems, and more and more stressing operator training needs. The T&E Community must evolve with the systems and structure the evaluation performance in step with the newly imbedded technology.

<u>Flexible</u> – Being able to address whatever new requirements are implied with the improvements or upgrades to the systems.

<u>Meaningful</u> – Bringing to the event the regiment and expertise already being applied to legacy systems, validated test objectives and measures of effectiveness, suitability and performance.

<u>Repeatable</u> – The T&E community must be able to sustain a benchmark for regression of each system. Core

capabilities may be improving, but each ships system was designed to support a specific mission. No matter what the change in computer program architecture or system hardware improvement, the ships system must fulfill its mission. Regression testing insures compliance, and repeatability. The T&E community must be capable of evaluation of performance to verify core functionality and the ability of the system to satisfy its mission.

Innovation – The T&E community must find solutions for difficult scenarios blending a mix of live and modeled testing to gauge system performance, and to also provide a value-added operational feel for the warfighter. OA brings the promise of greatly enhanced and rapidly upgradeable systems, and with that promise comes the need for creative and innovative T&E solutions.

Expertise/Lessons-Learned – The T&E professional workforce, who is the backbone for conducting modern-day T&E, must ensure that the collective knowledge for the business of test and evaluation is recorded, and passed on to the next generation T&E professionals. The AEGIS T&E community has evolved with a regiment and infrastructure based on lessons learned over the last 23 years of system test and certification. As the AEGIS program puts to sea its final ships and the AEGIS Weapon System reaches a final configuration, the AEGIS T&E community of practice must be preserved and applied to future, and evolving systems.

Cost Effective – T&E must provide meaningful and measurable metrics, which demonstrate conclusively, the merit to T&E. The pitfalls and tradeoffs from inadequate testing must be readily available to help tomorrow's

decision makers to defend the level and appropriateness of T&E in the future.

Technology Adopters – T&E must leverage technology wherever and whenever possible as a workforce multiplier, and a resource-saver. Just as future weapon systems embrace technology to provide new answers to difficult problems, so should future test and evaluation. Up front investments in technology are needed to ensure this happens.

Safety - Weapon system test execution must remain safe. Weapon system complexity challenges the DOD's ability to design scenarios to adequately understand the performance-related aspects of systems undergoing test. Regardless of testing complexity, safety cannot ever be compromised. Pressure to reduce safety standards and practices to expedite programs, and thereby reduce costs, must be resisted.

Environmental Compliance - Weapon system test execution must be in compliance with environmental laws and policies. At-sea testing is restrictive and difficult to characterize the impact to the environment. New future weapon technologies bring the challenge of additional review for environmental compliance. Increased weapon system complexity further challenges our understanding and ability to estimate impact upon the environment. The time and costs associated with adequate environmental review are prerequisite, and cannot be avoided.

Test Where It Makes Sense - Current sea-based test ranges typically involve test areas instrumented for live-fire exercises out to 100 nautical miles offshore.

Increased weapons system lethality, range, and performance are features of most future navy weapon systems. To adequately test these systems at-sea without compromising safety and environmental policies, the testing is being pushed further offshore, away from traditional land-centric test range infrastructure. Because offshore waters are being encroached more and more by commercial and private boat traffic and air traffic, adequate test areas free from encroachment must be pushed further away from traditional land-based test ranges. Future testing will need to be conducted in open-ocean areas using both remote and autonomous test procedures/capabilities. Major development and investment in unmanned systems operations is needed to make possible open-ocean testing. Telemetry (data collection) systems will be particularly challenging. New open-ocean test areas might need 200-400 nautical miles of instrumented range. This requires both a major cultural change as well as increased T&E funding resources.

Affordable - T&E processes and approaches can be cost-effective, yet still be unaffordable. The costs of testing current and future weapon technologies have been increasing for more than two decades. The ability to preserve costly special purpose test assets, test processes, and unique test range infrastructure is getting more difficult and challenging. T&E complexity is directly proportional to weapon system complexity. To remain affordable, T&E Programs are now expected to "get-it-right" the first time to keep costs affordable and manageable. But, T&E affordability cannot be measured in the test infrastructure costs, but rather, weapon system life-cycle costs. Affordable T&E should be measured by the degree total

weapon system life-cycle costs are minimized and reduce associated risks.

B. CONCLUSIONS

Test and Evaluation of ships systems verify that the Navy gets what it paid for, and the systems perform the mission they were designed to do. Cost effectiveness and expedience in the face of evolving technology are the hallmarks of a good T&E community. The lives of those who operate and maintain today's weapon systems depend on solid and reliable testing, to ensure systems do what they were designed to do. The T&E community makes it possible.

In a letter to the editors of Scientific American (Sawyer, 2003, p. 20) in response to an earlier article entitled, "Misguided Missile Shield", the writer states, "a demand for perfect realism in testing a complex weapon system like missile defense is unrealistic. More testing in necessary – more tests, however, are scheduled." Indeed it would seem that testing of as many of the variables possible is prudent, until the T&E community can respond with more comprehensive and full-scale tests in environments which mirror the conditions anticipated where these future weapon systems will be operated by tomorrow's warfighters.

C. SUGGESTED TOPICS FOR FUTURE RESEARCH

This research provided a historical account of several ongoing and emerging Navy T&E programs with the goal being to provide a series of attributes T&E must exhibit to

successfully field future systems. While touching on certain indicators and spending some focus on AEGIS Weapon System development and open architecture, the following topics are areas that should be considered for future research.

- **Analyze "lessons learned" from evolutionary acquisition to show how programs are balancing new capabilities and lifecycle support against T&E abilities and needs.** T&E must evolve and transform to provide continuous test windows inside the systems development, as well as being as operational as possible.
- **Assess the progress of AEGIS Open Architecture, and show mapping against Navy Open Architecture.** As standards are continually being developed and vetted out in the technical community, the real success lies in bringing actual open systems direct to the warfighter. Before this can happen however, these standards must be agreed upon and current and emerging systems will have to adopt them unilaterally.
- **Compare and contrast the decision to convert the AEGIS Fleet into an open systems baseline, versus bringing the AEGIS Weapon System into a "caretaker" status.** At present, the future baseline configuration for both AEGIS Cruisers and AEGIS Destroyers is still a matter of great debate, and very much dependent on future budgetary decisions and an unstable political horizon.
- **Evaluate the challenges of providing effective joint and allied systems T&E.** In addition, explore the need

for consistent interoperability standards, and how open systems development may help or hinder the interoperability crisis plaguing many major in-service weapons systems today.

- **Research a case example such as DD(X) as a "cradle to grave" open architecture program currently undergoing requirements generation and definition phase**. Explore the techniques for building an open computing environment that will incorporate test and evaluation inside the actual tactical code.

The 1970 Blue Ribbon Defense Panel, also know as the Fitzhugh Commission, took a very serious and in-depth review of defense acquisition policies and procedures. Their finding led to sweeping recommendations, which changed modern acquisition well before the term "evolutionary acquisition" was coined. This Commission also made profound recommendations concerning T&E, which actually led to the establishment of both the office overseeing DT&E as well as OT&E. In the thirty plus years since the Fitzhugh Commission made their recommendations, much has changed, but a few things have remained the same. The T&E community must never forget the principal reason for testing is to learn and to gain knowledge and information about the system undergoing design and development. No matter how "open" the system becomes, this need to learn remains, and testing at the lowest level, to the highest (operational) level is key. But testing must be done by experienced professionals using proven methods

and given adequate recourses. Is the current T&E infrastructure ready to handle the challenges that lie ahead?

The current Director of Operational Test and Evaluation recently concluded his remarks on T&E Role in Experimentation with the following:

> We, the T&E community – in both industry and government, both technical and operational testers – have served the Department very well over the years.
>
> There is a new world dawning that calls for new and innovative strategies and capabilities for T&E. I am confident that, together, we will rise to the challenge as we have in the past and ensure that our soldiers, sailors, and airmen are equipped with the best equipment our nation can provide (Christie, "Test & Evaluation's Role in Experimentation," 2002.)

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